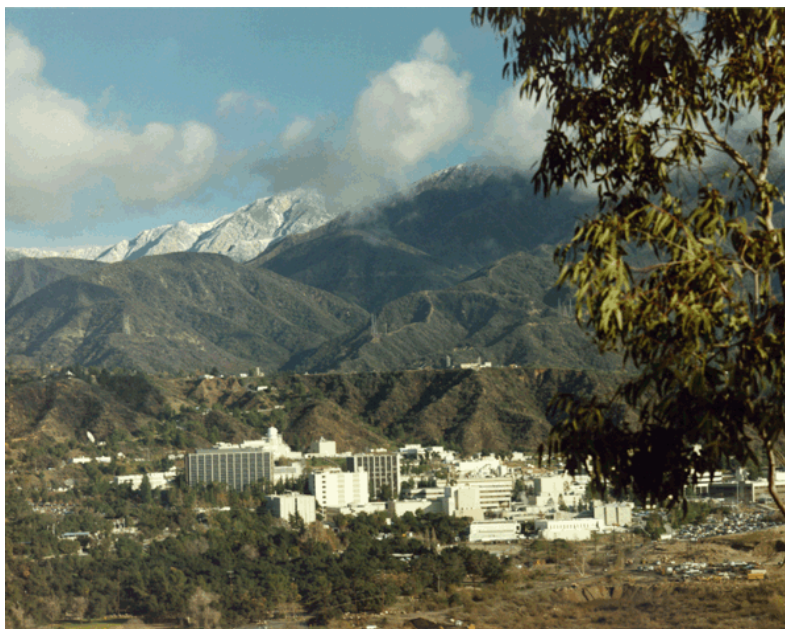**FINAL**

**INTERIM RECORD OF DECISION
FOR THE OPERABLE UNIT 1 SOURCE AREA GROUNDWATER**

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JET PROPULSION LABORATORY
PASADENA, CALIFORNIA**

EPA ID# CA9800013030

PREPARED FOR:

**National Aeronautics and Space Administration
Management Office, Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91109**

December 2006

Part I: DECLARATION

Site Name and Location

SITE NAME: Jet Propulsion Laboratory (JPL)

EPA ID NUMBER: CA9800013030; Federal Facility Agreement Docket
                                  Number 1998-27

LOCATION: 4800 Oak Grove, Pasadena, California

SITE TYPE: Federal Facility; Government-owned, contractor-operated

LEAD AGENCY: National Aeronautics and Space Administration (NASA)

SUPPORTING AGENCIES: U.S. Environmental Protection Agency (U.S. EPA), Region
                                  9; State of California Environmental Protection Agency
                                  (Cal/EPA), Department of Toxic Substances Control
                                  (DTSC); and California Regional Water Quality Control
                                  Board (RWQCB), Los Angeles Region

OPERABLE UNIT: Operable Unit 1 (OU-1), Source Area Groundwater

Statement of Basis and Purpose

This document is published as an Interim Record of Decision (ROD) under the Comprehensive
Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), 42 United States
Code (USC) § 9601 et seq. This decision document presents the response action selected by
NASA and the supporting agencies (U.S. EPA, DTSC, and RWQCB) for the OU-1 source area
at JPL. The response action was selected in accordance with CERCLA, as amended by the
Superfund Amendments and Reauthorization Act of 1986 (SARA), and to the extent practicable,
the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), 40 Code of
Federal Regulations (CFR) 300.400 et seq. and California Health and Safety Code (HSC) §
25356.1. The response action was selected based upon information available in the
Administrative Record.

The supporting agencies, consisting of U.S. EPA, DTSC, and the RWQCB, concur with the
response action recommended in this ROD.

Assessment of the Site

The response action selected in this ROD is expected to achieve protection of human health and the environment from actual or threatened releases of hazardous substances into the environment.

Description of the Selected Remedy

In October 1992, JPL was placed on the National Priorities List (NPL) and, therefore, is subject to the provisions of CERCLA. The JPL site has been divided into three OUs. OU-1 is on-facility groundwater at JPL; OU-2 is on-facility vadose zone soil at JPL; and OU-3 is off-facility groundwater adjacent to the JPL property. This interim decision document addresses source area groundwater within OU-1. The ROD for OU-2 was signed in September 2002 and remedial action using soil vapor extraction (SVE) is underway (NASA, 2002). Another response action has been proposed by NASA for OU-3 to clean up the chemicals located adjacent to and in deep groundwater beneath JPL using wellhead treatment. NASA will conduct an integrated Feasibility Study in the future to evaluate the overall effectiveness of all the response actions for groundwater and to determine whether additional cleanup measures are required for on- and off-facility groundwater.

A human health baseline risk assessment and a preliminary assessment of ecological risk were conducted as part of the OU-1 and OU-3 Remedial Investigation (RI) to evaluate the potential risks associated with hypothetical exposure to chemicals in the untreated groundwater beneath the JPL facility. The baseline risk assessment identified eleven (11) chemicals as contributors to a cancer risk greater than 10^{-6} or a hazard index greater than 0.5 under a drinking water scenario. These chemicals included: arsenic, hexavalent chromium, nitrate, perchlorate, bromodichloro-methane, carbon tetrachloride, chloroform, 1,1-dichloroethene, 1,2-dichloroethane, tetrachloro-ethene, and trichloroethene (Foster Wheeler Environmental Corporation [FWEC], 1999a). It is important to note that because groundwater is in a deep aquifer and water purveyors treat groundwater before use, no complete pathway for exposure to these chemicals exists.

The highest concentrations of carbon tetrachloride and perchlorate at the JPL site are located in the north-central portion of the JPL facility, which is referred to as the "source area." The source area is the location where the majority of target chemicals are dissolved in the groundwater, and is defined as an 8-acre by 100-ft-thick portion of the aquifer. The response action for OU-1 consists of expansion of the existing source area demonstration study system which provides treatment and containment using groundwater extraction, aboveground treatment, and reinjection. This process will improve the effectiveness and efficiency of the OU-3 groundwater remedy by reducing chemical mass in groundwater that migrates off-facility. This action is part of a phased approach to characterization and cleanup of groundwater affected by chemicals originating from the JPL facility. A phased approach to cleanup is encouraged by Superfund Accelerated Cleanup Model (SACM) (U.S. EPA, 1992a), whereby characterization and performance data collected during initial phases are used to assess restoration potential. Groundwater restoration potential refers to the likelihood of achieving applicable or relevant and appropriate requirements (ARARs) throughout the facility.

Interim ROD, OU 1 Source Area Groundwater   iii   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part I: Declaration

A demonstration study system began operation in March 2005 to evaluate treatment effectiveness and has proven to be highly effective. This response action will expand the existing demonstration study treatment system associated with the source area beneath the JPL facility. Major components of the Interim Action include:

- groundwater extraction from the source area.

- aboveground groundwater treatment using liquid-phase granular activated carbon (LGAC) to remove volatile organic compounds (VOCs) and a fluidized-bed reactor (FBR) to remove perchlorate.

- reinjection of treated water.

The implementation of source treatment is consistent with the U.S. EPA's presumptive response strategy for sites requiring groundwater cleanup (U.S. EPA, 1996). Also, the U.S. EPA has identified presumptive technologies for treatment of extracted groundwater containing VOCs (U.S. EPA, 1996). The presumptive technologies include air stripping and LGAC. According to the U.S. EPA, these technologies are presumptive for treatment of VOCs in groundwater that has been extracted from the subsurface, and are expected to be used for this purpose at "all appropriate sites" (U.S. EPA, 1996). The benefits of presumptive technologies include: a simplified selection process, elimination of technology screening, and focusing resources on fundamental aspects of groundwater cleanup.

Statutory Determinations

This response action is protective of human health and the environment in the short term and is intended to provide adequate protection until a final ROD is signed; complies with those federal and state requirements that are applicable or relevant and appropriate for this limited-scope action; and is cost-effective. Although this response action is not intended to address fully the statutory mandate for permanence and treatment to the maximum extent practicable, this response action uses treatment and thus supports the statutory mandate. Because this action does not constitute the final remedy for OU-1, the statutory preference for remedies that employ treatment to reduce toxicity, mobility, or volume as a principal element, although partially addressed in this remedy, will be addressed by the final response action. Subsequent actions are planned, in a phased approach, to address fully the threats posed by conditions in groundwater at the JPL facility.

Because this response action may result in chemicals remaining in on-facility groundwater above health-based levels, a review will be conducted every five years to ensure that the remedy continues to provide adequate protection of human health and the environment. This first review is required five years after finalizing the first ROD for the site. The ROD for OU-2 was signed in September 2002 (See, 42 USC 9621(c)); therefore, the first five-year review will be conducted in 2007.

ROD Data Certification Checklist

The following information is included in Part II: Decision Summary of this ROD. Additional information can be found in the Administrative Record.

- Chemicals and their concentrations in source area groundwater, Section 5.0

- Baseline risk represented by the chemicals in on-facility groundwater, Section 7.0

- Interim action performance objectives for the chemicals in source area groundwater, Sections 8.0 and 11.0

- How chemicals in source area groundwater will be addressed, Section 11.0

- Current and reasonably anticipated future land use assumptions, Section 6.0

- Current and potential future beneficial uses of groundwater, Section 6.0

- Potential land and groundwater use that will be available as a result of the response action Section 11.0

- Estimated capital, annual operation and maintenance (O&M) and total present worth costs, Section 11.0

- Number of years that response action is expected to operate, Sections 9.0 and 11.0

- Key factors that lead to selecting the response action, Sections 9.0, 10.0, 11.0, and 12.0.

Interim ROD, OU 1 Source Area Groundwater   v   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part I: Declaration

**FOR THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JET PROPULSION LABORATORY:**

(signature)   12/07/06
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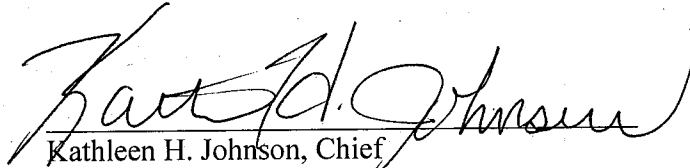Dr. Eugene Trinh, Director   Date
NASA Management Office
Jet Propulsion Laboratory

FOR THE U.S. ENVIRONMENTAL PROTECTION AGENCY:

Kathleen H. Johnson, Chief
Federal Facilities and Site Cleanup Branch
Superfund Division
U.S. Environmental Protection Agency, Region 9

2/8/07
Date

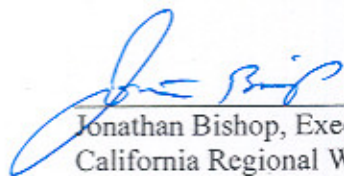**FOR THE STATE OF CALIFORNIA:**

_____

Sayareh Amir, Chief

Southern California Cleanup Operations, Glendale Office

Department of Toxic Substances Control

12-27-06

_____

Date

FOR THE STATE OF CALIFORNIA:

Jonathan Bishop _____   3/7/07
Jonathan Bishop, Executive Officer   Date
California Regional Water Quality Control Board
Los Angeles Region

CONTENTS

Interim ROD, OU 1 Source Area Groundwater   x   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Contents

Interim ROD, OU 1 Source Area Groundwater   xi   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
                                 Contents

APPENDICES

APPENDIX A: Administrative Record Index for OU-1
APPENDIX B: Public Notices

FIGURES

TABLES

Interim ROD, OU 1 Source Area Groundwater   xii   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Contents

ACRONYMS AND ABBREVIATIONS

ARAR   Applicable or Relevant and Appropriate Requirement(s)
ATSDR   Agency for Toxic Substances and Disease Registry

BDAT   best demonstrated available technology
bgs   below ground surface

Cal/EPA   State of California, Environmental Protection Agency
Caltech   California Institute of Technology
CCl_4 carbon tetrachloride
CCR   California Code of Regulations
CERCLA   Comprehensive Environmental Response, Compensation, and Liability
            Act of 1980
CFR   Code of Federal Regulations
COPC   chemical of potential concern
Cr^{+6} hexavalent chromium
CSTR   Continuously Stirred Tank Reactor
CWC   California Water Code

DCA   dichloroethane
DCE   dichloroethene
DHS   (California) Department of Health Services
DTSC   Department of Toxic Substances Control

ERA   ecological risk assessment
EW   extraction well

FBR   fluidized-bed reactor
FFRDC   Federally-Funded Research and Development Center
FWEC   Foster Wheeler Environmental Corporation

gpm   gallons per minute

HI   hazard index
HHRA   human health risk assessment
HQ   hazard quotient
HSC   (California) Health and Safety Code

ISB   In Situ Bioremediation
IW   (re)injection well

JPL   Jet Propulsion Laboratory

ABBREVIATIONS AND ACRONYMS (Continued)

LDR	land disposal restriction
LGAC	liquid-phase granular activated carbon
MCL	maximum contaminant level
µg/L	microgram per liter
MW	monitoring well
NASA	National Aeronautics and Space Administration
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEPA	National Environmental Policy Act of 1969
NFA	no further action
NL	notification level
NPL	National Priorities List
O&M	operation and maintenance
OU	operable unit
PBR	Packed Bed Reactors
PCE	tetrachloroethene
PHG	Public Health Goal
PNDM	nitrate catalytic destruction module
R&D	research and development
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RO	reverse osmosis
ROD	Record of Decision
RWQCB	Regional Water Quality Control Board
SACM	Superfund Accelerated Cleanup Model
SARA	Superfund Amendments and Reauthorization Act of 1986
SDWA	Safe Drinking Water Act
SVE	soil vapor extraction
SVOC	semivolatile organic compounds
TCE	trichloroethene
UCL	upper confidence level
USC	United States Code
U.S. EPA	United States Environmental Protection Agency

ABBREVIATIONS AND ACRONYMS (Continued)

VOC   volatile organic compound

WDR   waste discharge requirement

Interim ROD, OU 1 Source Area Groundwater   xv   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Acronyms and Abbreviations

Part II: DECISION SUMMARY

1.0: SITE NAME, LOCATION, AND DESCRIPTION

SITE NAME: Jet Propulsion Laboratory (JPL)

EPA ID NUMBER: CA9800013030; Federal Facility Agreement Docket Number 1998-27

LOCATION: 4800 Oak Grove, Pasadena, California

SITE TYPE: Federal facility; Government-owned, contractor-operated

LEAD AGENCY: National Aeronautics and Space Administration (NASA)

SUPPORTING AGENCIES: U.S. Environmental Protection Agency (U.S. EPA), Region 9; State of California Environmental Protection Agency (Cal/EPA), Department of Toxic Substances Control (DTSC); and California Regional Water Quality Control Board (RWQCB), Los Angeles Region

OPERABLE UNIT: Operable Unit 1 (OU-1), Source Area Groundwater

NASA is the lead federal agency for selecting, implementing, and funding remedial activities at JPL, while U.S. EPA, DTSC, and RWQCB provide oversight and technical assistance.

The JPL is a federally-funded Research and Development Center (FFRDC) in Pasadena, California, currently operated under contract by the California Institute of Technology (Caltech) for NASA. JPL's primary activities include the exploration of the earth and solar system by automated spacecraft and the design and operation of the Global Deep Space Tracking Network.

Located in Los Angeles County, JPL adjoins the incorporated cities of La Cañada Flintridge and Pasadena, and is bordered on the east by the unincorporated community of Altadena. A NASA-owned facility, JPL encompasses approximately 176 acres of land and more than 150 buildings and other structures. Of the JPL Facility's 176 acres, approximately 156 acres are federally owned. The remaining land is leased for parking from the City of Pasadena and the Flintridge Riding Club. Development at JPL is primarily located on the southern half, in two regions, an early-developed northeastern area and a later-developed southwestern area. Figure 1-1 is a map showing the JPL facility and surrounding areas.

Interim ROD, OU 1 Source Area Groundwater   1   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary
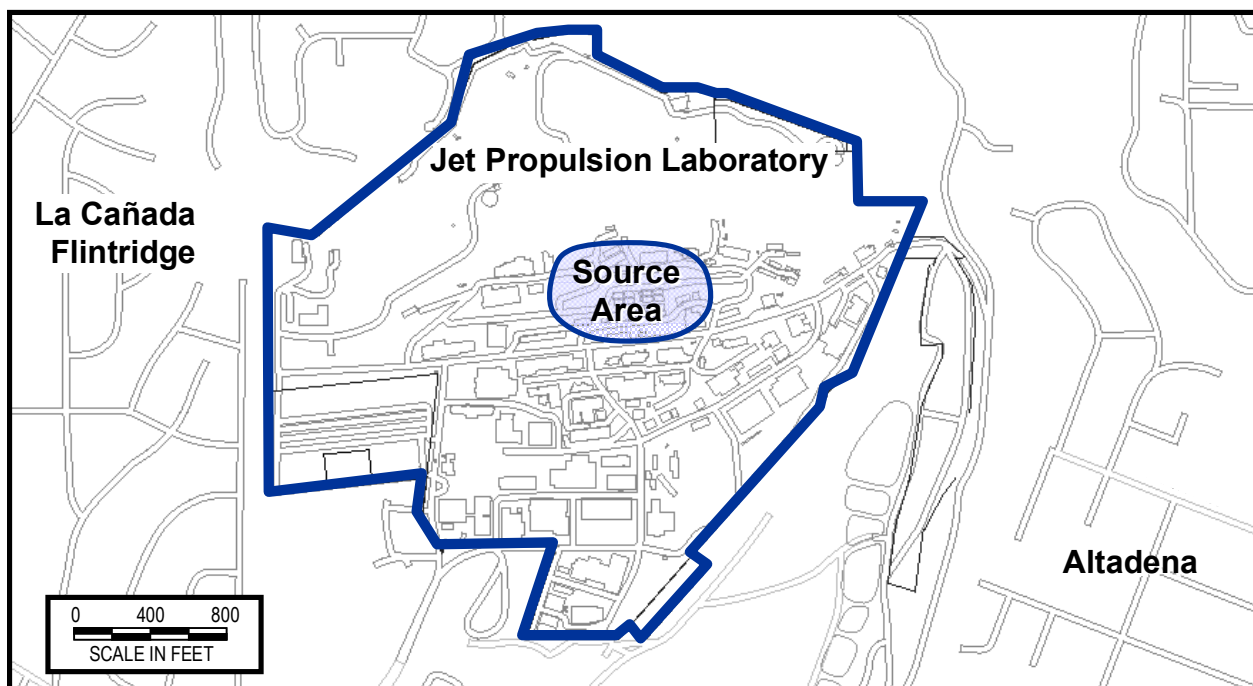
Figure 1-1. Map of JPL and the Surrounding Area

Interim ROD, OU 1 Source Area Groundwater   2   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

2.0: SITE HISTORY

During historic operations at JPL, various chemicals (including chlorinated solvents, solid rocket fuel propellants, cooling tower chemicals, sulfuric acid, Freon™, and mercury) and other materials were used at the JPL facility. During the 1940s and 1950s, many buildings at JPL maintained subsurface seepage pits for disposal of sanitary wastes and laboratory chemical wastes collected from drains and sinks within the buildings. The Remedial Investigation (RI) for OU-2 identified 40 seepage pits, five waste pits, and four discharge points at the facility that were used during historic operations (Foster Wheeler Environmental Corporation [FWEC], 1999b). Some of the seepage pits received volatile organic compounds (VOCs) and other waste materials which are currently found in groundwater beneath and adjacent to JPL. In the late 1950s and early 1960s, a sanitary sewer system was installed at JPL to handle sewage and wastewater, and the use of seepage pits for sanitary and chemical waste disposal was discontinued. Today, laboratory chemical wastes are either recycled or sent off-facility for treatment and disposal at regulated, Resource Conservation and Recovery Act (RCRA)-permitted hazardous waste facilities.

In 1980, the analyses of groundwater revealed the presence of VOCs in City of Pasadena water-supply wells located southeast of JPL in the Arroyo Seco. At about the same time, VOCs were detected in two water-supply wells used by the Lincoln Avenue Water Company, located east of the Arroyo Seco (FWEC, 1999a). As a result, NASA initiated investigation to evaluate VOCs originating from the JPL facility.

In 1988, a Preliminary Assessment/Site Inspection was completed at JPL, which indicated that further site characterization was warranted (Ebasco, 1988). Subsequent site investigations were conducted at JPL (Ebasco, 1990a; Ebasco, 1990b) and VOCs were detected in on-facility groundwater at levels above drinking water standards. In 1992, JPL was placed on the National Priorities List (NPL) of sites subject to regulation under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (47180-47187 *Federal Register*, Vol. 57, No. 199 (1992)).

After being placed on the NPL, the nature and extent of chemicals in groundwater were investigated during the RI, which lasted from 1994 to 1998 (FWEC, 1999a; FWEC, 1999b). Additional groundwater data have been obtained from a long-term groundwater monitoring program in place at the facility since August 1996, which continues to be active. Based on the data collected during the RI and long-term groundwater monitoring, two VOCs (carbon tetra-chloride and trichloroethene [TCE]) and perchlorate have been detected consistently in the source area at concentrations significantly exceeding their respective state or federal maximum contaminant levels (MCLs) or California Department of Health Services (DHS) notification levels (NLs). The highest concentrations of carbon tetrachloride and perchlorate at the JPL site are located in the north-central portion of the JPL facility, which is referred to as the "source area." The source area is the location where the majority of chemicals is dissolved in the groundwater, and is defined as an 8-acre by 100-ft-thick portion of the aquifer.

Interim ROD, OU 1 Source Area Groundwater   3   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

In the late 1990s and early 2000, NASA conducted pilot testing of several technologies to address dissolved perchlorate in source area groundwater. The technologies tested included reverse osmosis, a fluidized bed reactor (FBR), packed bed reactors, in situ bioremediation, and ion exchange (FWEC, 2000; NASA, 2003a). Due to the depth and extent of the chemicals in groundwater, in situ (below ground) treatment is not cost-effective at the JPL facility; therefore, groundwater must be pumped from the ground, treated aboveground, and reinjected.

Based on these studies, NASA installed a demonstration treatment plant located on JPL in the source area in early 2005 (NASA, 2003a; NASA, 2005b). The demonstration study area location is illustrated in Figure 2-1. The demonstration study consists of two extraction wells, two injection wells, liquid-phase granular activated carbon (LGAC) treatment to remove VOCs, and an FBR to remove perchlorate, as depicted in Figure 2-2. This system has been successful in the demonstration phase (NASA, 2005c; NASA 2005d; NASA, 2006a). This ROD documents expansion and continued operation of the demonstration system as the response action, as shown in Figures 2-1 and 2-2.
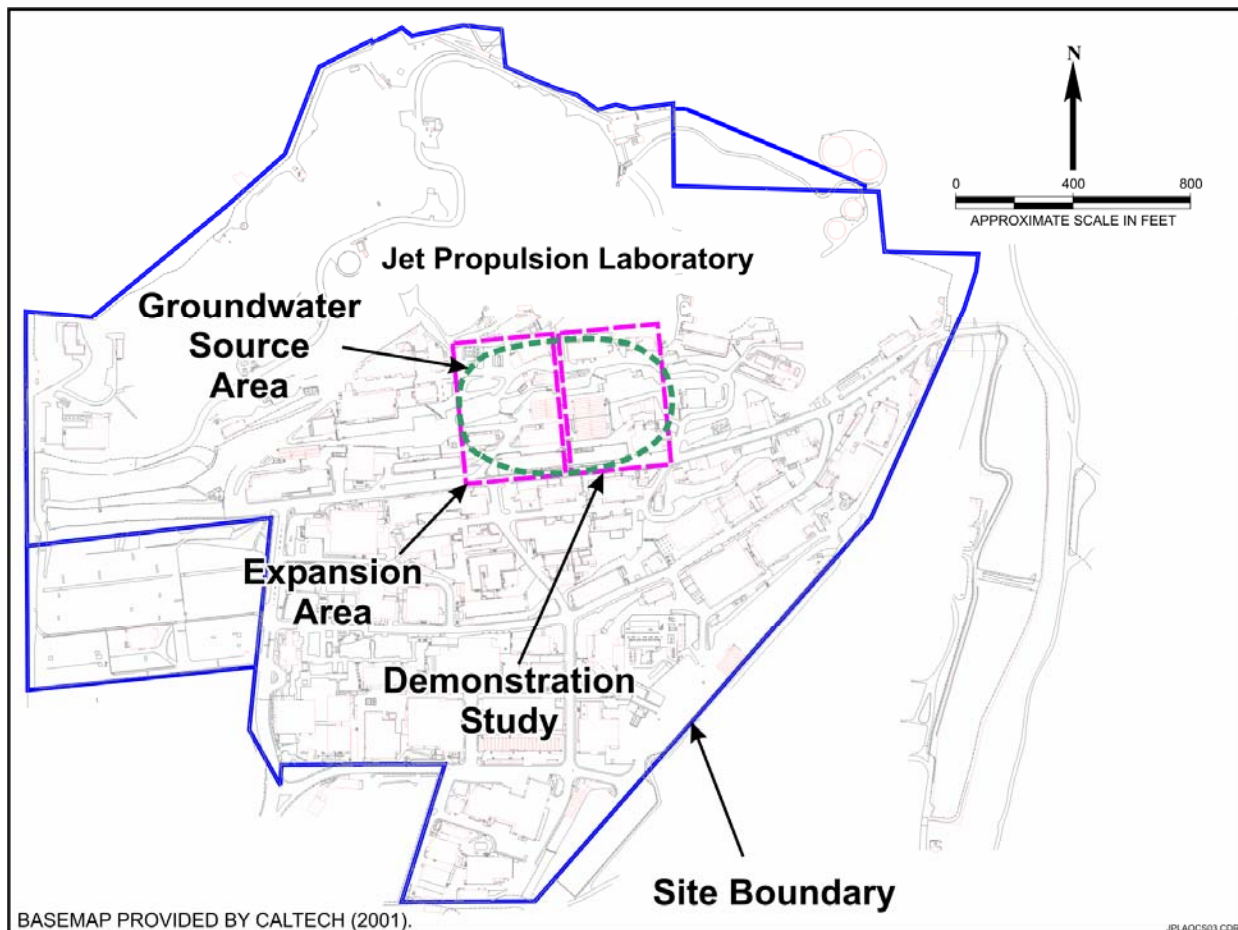
**Figure 2-1. Location of the Existing Source Area
Groundwater Demonstration Study**

Interim ROD, OU 1 Source Area Groundwater   4   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary
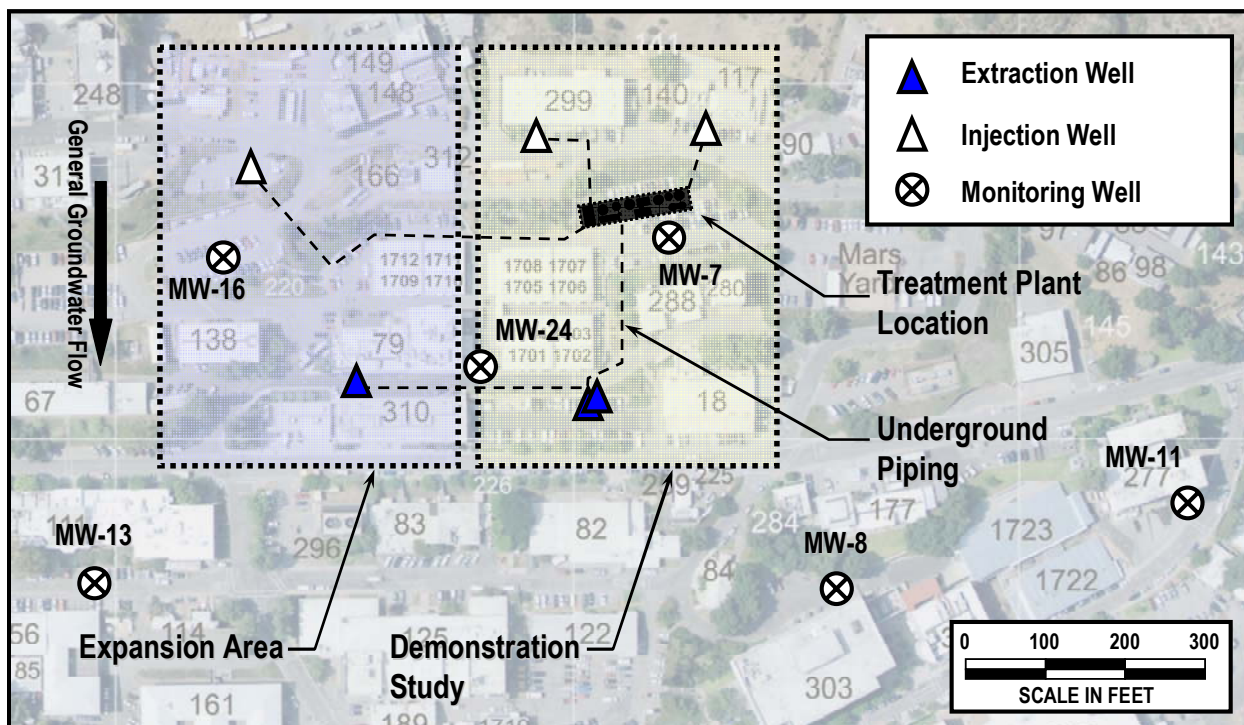
Figure 2-2. Layout of the Existing Demonstration System and the Expansion Area

3.0: COMMUNITY PARTICIPATION

All CERCLA documentation associated with the JPL site is available to the public at the following Web site: http://jplwater.nasa.gov. The Proposed Plan for OU-1 at NASA JPL (NASA, 2005a) and supporting documents were made available to the public via the Administrative Record maintained at JPL and the information repositories maintained at the JPL Library, Altadena Public Library, the La Cañada Flintridge Public Library, and the Pasadena Central Library. The index to the Administrative Record for OU-1 is included in Appendix A.

NASA has held several public meetings and community information sessions during the past two years to inform the communities surrounding JPL about the progress of environmental programs at JPL. The methods used by NASA to ensure that communities are properly informed and included in the CERCLA process are described in the *Superfund Community Relations Plan* (NASA, 1994) and *Community Relations Plan: Amendment 1* (NASA, 2003b).

In January 2004, public meetings were held to inform the public about the progress of remedial activities and current status of each operable unit. NASA's plan for an expanded treatability study using an FBR to treat perchlorate in groundwater beneath the JPL facility (i.e., OU-1) was discussed at these meetings, as well as the current status of work on OU-2 and OU-3. A newsletter summarizing this information and noting the upcoming meetings was mailed in January 2004 to nearly 15,000 residents of communities surrounding the JPL facility.

In April 2004, another public meeting was held to present information to the public regarding potential public health impacts due to chemicals in the groundwater from the JPL facility. A more recent community information session was held in March 2005 to again update the public about the current status of each OU. Designed to be a more interactive, informal meeting, the evening provided an opportunity for attendees to speak one-on-one with project leaders and members of NASA's environmental team at different poster displays and ask questions about the cleanup effort.

Public notifications of the Proposed Plan (NASA, 2005a) and a November 16, 2005, public meeting were mailed to approximately 17,000 residences, businesses, and organizations in Altadena, La Cañada Flintridge, and Pasadena, and were e-mailed to approximately 5,000 JPL employees. Public notification of the November 16, 2005, meeting also was provided in local newspaper notices, including the *Pasadena Weekly* (November 10, 2005) and the *Pasadena Star-News* (November 1, November 9, and November 15, 2005). The text of these public notices is included in Appendix B. The required pubic meeting was held on November 16, 2005, midway through the public comment period (November 1, 2005, through December 15, 2005) and was attended by more than 30 people. The transcript from this meeting may be found at the information repositories or on the Web site http://jplwater.nasa.gov. Prior to the meeting, an information session was held to provide an opportunity for community members to talk one-on-one with the NASA team and better understand the CERCLA program at JPL.

NASA's responses to the comments received during the Proposed Plan public comment period are included in Part III of this ROD, the Responsiveness Summary.

Interim ROD, OU 1 Source Area Groundwater   6   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

4.0: SCOPE AND ROLE OF RESPONSE ACTION

This ROD addresses source area groundwater treatment and containment in OU-1, which comprises the groundwater located in the north-central area and directly beneath the JPL facility (see Figure 1-1). Remediating the source area is an element of the overall site cleanup strategy for restoring the aquifer. NASA has defined the source area groundwater as the 8-acre by 100-ft-thick portion of the aquifer where chemicals (specifically, carbon tetrachloride and perchlorate) have been found at concentrations over 100 times their respective MCL and notification level. It is estimated that more than 60% of the dissolved chemical mass present at the facility is located within the source area, and that it represents less than 3% of the total volume of impacted groundwater. Source area groundwater treatment and containment will improve the effectiveness and efficiency of the groundwater remedy for OU-3 by significantly reducing chemical mass in groundwater that migrates off-facility.

In addition, SVE was implemented to clean up VOCs in the on-facility soils (OU-2) (NASA, 2002). Implementation of this remedy not only addressed remediation of soil, but also enhanced the overall site cleanup strategy by removing VOCs from the vadose zone, thus reducing the source of VOCs that may migrate to the groundwater.

> Remediating the source area is a critical part of the overall site strategy for restoring the aquifer because the majority of the chemical mass that would eventually migrate to the nearby drinking water wells is located within this area.

NASA's proposed approach for remediating OU-3, off-facility groundwater, consists of wellhead treatment. NASA has funded a treatment system to remove VOCs and perchlorate from two Lincoln Avenue Water Company drinking water wells and has proposed a similar system for four City of Pasadena drinking water wells (NASA, 2006b). Effective source area treatment will reduce the duration that these larger, more expensive treatment systems in OU-3 will need to operate.

The overall site management plan thus takes into account the interrelationship of the three OUs. Figure 4-1 illustrates how the response action fits into the overall remedial site strategy.
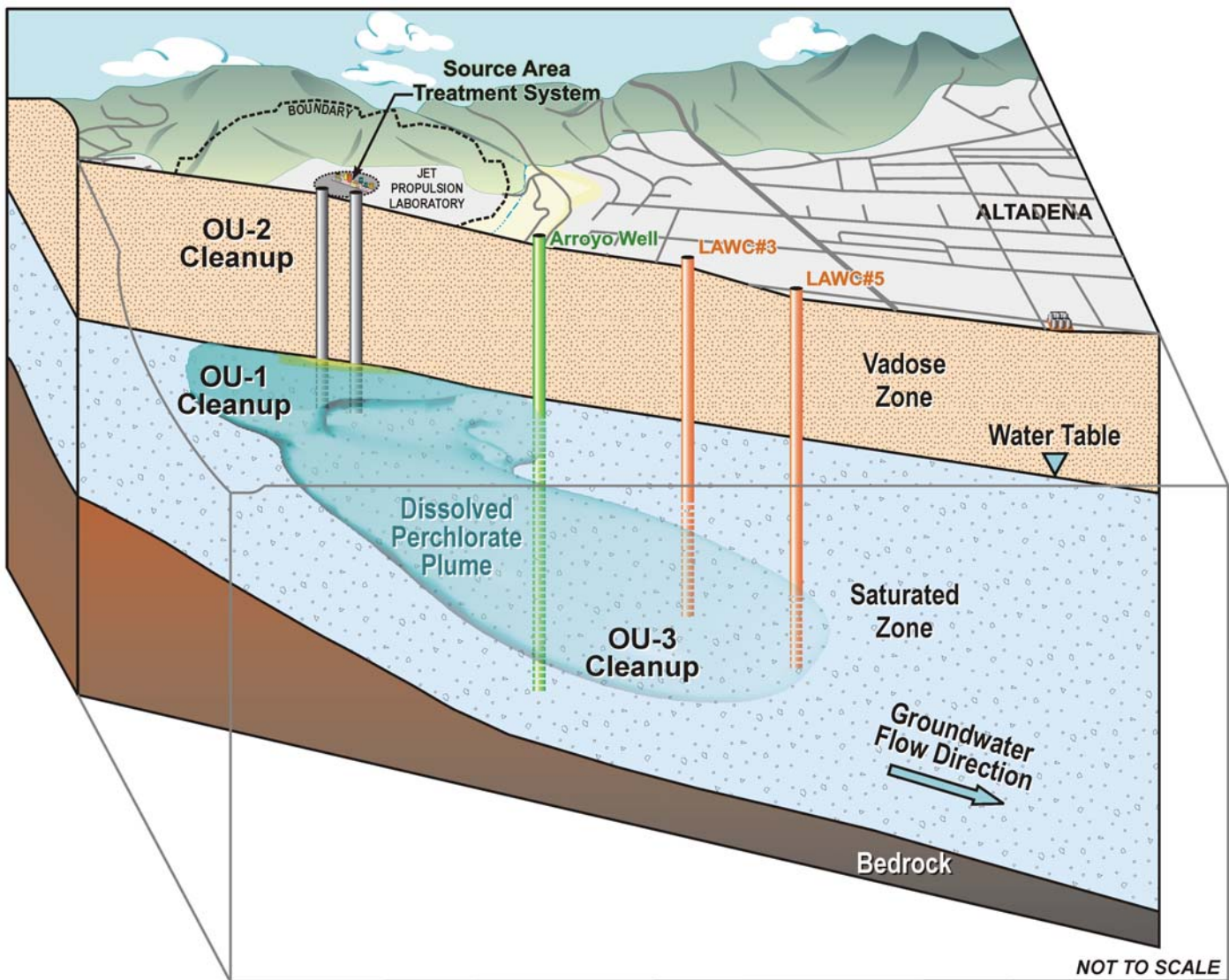
Figure 4-1. OU-1 Source Area Groundwater Remediation is an Important Component of the Overall Site Strategy

5.0: SITE CHARACTERISTICS OF OPERABLE UNIT 1 SOURCE AREA

This section presents a brief overview of the OU-1 site, including a description of the aquifer and groundwater flow, chemicals in groundwater, demonstration study results, and the conceptual site model.

5.1   JPL and Operable Unit 1 Area Setting

An in-depth description of the area setting of OU-1, including a detailed discussion of the regional demographics, climate, physiography, geology, hydrology, hydrogeology, natural resources, and cultural resources can be found in the *National Environmental Policy Act of 1969 (NEPA) Values Assessment* (NASA, 2006c), and in the *Final Remedial Investigation (RI) for OU-1 and OU-3* (FWEC, 1999a).

> The source area groundwater is an 8-acre portion of the upper aquifer layer containing over 60% of the dissolved chemical mass present. Groundwater in this area has a southerly flow direction.

The aquifer beneath JPL is generally considered unconfined. The groundwater table is located approximately 200 ft below ground surface (bgs). Based on water level and soil-type data, the aquifer has been divided into four (4) "aquifer layers." The upper three aquifer layers are present beneath JPL, and the fourth layer is found in the bottom screen interval of the easternmost off-facility JPL monitoring well. Aquifer Layer 1 comprises the upper 75 to 100 ft of the aquifer and includes the water table. Aquifer Layers 2, 3, and 4 are separated from Layer 1 by thin silt-rich intervals, or aquitards, approximately 300, 500, and 800 ft deep, respectively (FWEC, 1999a). The OU-1 groundwater source zone consists of approximately 8-acres within Layer 1.

Groundwater flow patterns are complex, due primarily to pumping of the Pasadena municipal production wells near the JPL facility (FWEC, 1999a). Near the OU-1 source area, historical groundwater-level elevation data indicate a steep southwest gradient from the mouth of the Arroyo Seco to the OU-1 system area coupled with a southeast gradient from the northeast of JPL. Flow converges to the south of the treatment system and migrates toward the southeast. Data collected from the majority of historical groundwater monitoring events has shown a southerly flow in the vicinity of the system.

Groundwater flow is significantly affected by operation of the demonstration system, with a drawdown of roughly 25-30 ft observed in the extraction wells and radial flow observed toward these wells. Monitoring data indicate that that extraction wells will effectively contain ground-water within a 150-ft radius of the extraction wells and the groundwater injected upgradient at the injection wells (NASA, 2005b).

5.2   Sources of Chemicals in Groundwater at JPL

Various seepage pits and other areas were identified at JPL as possible locations used for chemical waste disposal during historic operations. In particular, solvents (including carbon tetrachloride and TCE) were widely used during historic operations at JPL, and the dozens of these seepage pits at which these chemicals were released are the likely source of chemicals

found in the source area groundwater at the JPL facility. Figure 5-1 shows the locations of 40 of these seepage pits, 11 of which are located above the groundwater source area addressed in this ROD. Table 5-1 provides the inferred use of these 11 disposal locations based on available records.

The nature and extent of VOCs, perchlorate, metals, and other organic constituents were determined through groundwater sampling conducted at the facility during the RI for OU-1 and OU-3. Groundwater samples were analyzed for a variety of organic and inorganic compounds and elements. Results in the RI and subsequent groundwater monitoring efforts show that VOCs, perchlorate, metals, and other organic constituents are present in groundwater beneath the JPL facility. Detailed information on the RI sampling strategy can be found in the RI report (FWEC, 1999a).
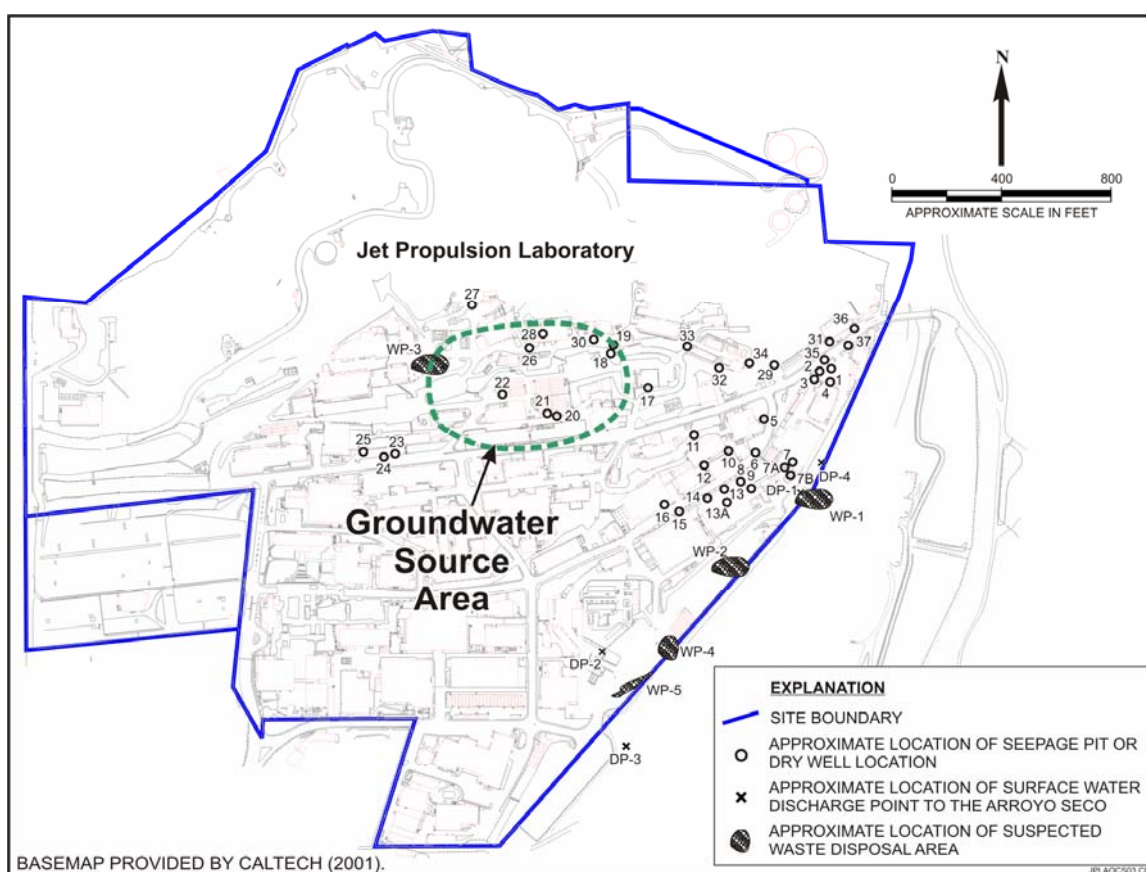
Figure 5-1. Potential Historical Chemical Waste Disposal Locations at the JPL Facility

**Table 5-1. Description of Waste Disposal Locations
Near the Groundwater Source Area**

Seepage Pit No.	Associated Building No.	Building Still Exists (Yes/No)	Current Area Use	Inferred Use
17	55	No	Parking lot near Building 280	Solid propellant mixing facility; solvents used to clean mixing hardware were disposed of by pouring into sumps prior to installation of sanitary sewer system.
18 & 19	90	Yes	Under Pioneer Road	Shop for test cell No. 51 (solid propellant testing in Test Cell "X"); test motors and hardware soaked in tubs of solvents (included perchlorate and acetone) that were not recycled and allegedly dumped into sumps on west side of Building 90 or at east end of solid propellant preparation area (east of Building 88).
20 & 21	63	No	Under or behind retaining wall foundations	Compressors and maintenance shop; solvents routinely used for parts cleaning.
22	80	No	Under office trailers	Wind tunnel building; no history of solvent or chemical usage.
26 & 28	77	No	Under Building 299, in planter or under Pioneer Road	Structure housed experimental chemistry lab and fluorine propellant test cell with an acid-neutralizing pit constructed similar to a dry well; numerous chemicals reportedly disposed by dumping into available sumps near building; seepage pit is upgradient from MW-7.
27	246	Yes	Asphalt paved parking area	Dry well from sink at former soils test laboratory; no history of solvent or chemical usage.
30	117	Yes	Asphalt paved parking area	Building housed former solid propellant test cell where solvents used to clean rocket motors and hardware, solvents reportedly not recycled and disposed of by dumping into nearby drains and sumps.
WP-3	119	No	Asphalt paved parking area	Former salvage storage area; solvents reportedly dumped into hand-dug holes.

5.3 Chemicals and Concentrations in Source Area Groundwater at JPL

Five monitoring wells are located in or near the OU-1 source area: MW-7, MW-8, MW-13, MW-16, and MW-24 (see Figure 2-2). All of these monitoring wells, except MW-24, are single screen wells. MW-24 is a deep multiport well with five separate screened intervals for sampling, with the uppermost Screen 1 roughly corresponding in elevation to the other source area

Interim ROD, OU 1 Source Area Groundwater   11   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

monitoring wells. During the initial phases of the RI, comprehensive suites of analyses were performed. These included VOCs, semivolatile organic compounds (SVOCs), Title 26 metals, additional metals analyses for strontium, aluminum, and hexavalent chromium (Cr^{+6}), cyanide, gross alpha/gross beta radiation; and total petroleum hydrocarbons. During the long-term monitoring, various analyses were added or dropped based on previous results or new information. Analyses during the long-term groundwater monitoring primarily included VOCs, metals [arsenic, lead, chromium (Cr and Cr^{+6})], tributyltin, 1,4-dioxane, n-nitrosodimethylamine, and perchlorate.

Several VOCs have been detected in the OU-1 source area monitoring wells above drinking water MCLs, including carbon tetrachloride, TCE,

> Based on sampling results collected over the past ten years from monitoring wells located in the source area, the primary chemicals of interest are chlorinated VOCs and perchlorate.

tetrachloroethene, 1,2-dichloroethane (1,2-DCA), and 1,1-dichloroethene (1,1-DCE). In addition, perchlorate has been consistently detected above the State Public Health Goal (PHG) and current notification level of 6 micrograms per liter (µg/L). Table 5-2 summarizes the detections of VOCs and perchlorate in the source area monitoring wells.

Carbon Tetrachloride
Concentrations of carbon tetrachloride have been reported in excess of the MCL (0.5 µg/L) in samples from all five source area monitoring wells during the past decade (see Table 5-2). The highest concentration of carbon tetrachloride was reported in well MW-7 at 208 µg/L (April 2002). Concentrations in this well have since declined, reaching below the MCL in August 2005 after the OU-1 demonstration source area treatment system began operating in February 2005. Carbon tetrachloride concentrations in MW-24 (Screen 1) similarly reached the MCL for the first time in November 2005 after the OU-1 demonstration system began operation. Figure 5-2 shows the carbon tetrachloride trend for the last four years in four source area monitoring wells. Carbon tetrachloride concentrations in source area monitoring wells MW-13 and MW-16 located farther from the demonstration treatment system remain above the MCL. The change of the carbon tetrachloride plume is illustrated in the performance reports using groundwater contour maps from before and after demonstration system installation (NASA, 2005d; NASA, 2006a).

Trichloroethene (TCE)
Reported TCE concentrations have exceeded the state and federal MCL (5.0 µg/L) in all five source area monitoring wells (see Table 5-2). The highest concentrations of TCE reported during the past decade occurred in September 1996 in wells MW-13 (47 µg/L), MW-7 (39 µg/L), and MW-16 (33 µg/L). Concentrations in these wells have since declined, and have remained below the MCL in MW-16 since 2001 and in MW-7 since the OU-1 demonstration system began operating in February 2005. TCE concentrations in MW-13 remain above the MCL. TCE concentrations in MW-24 are below the MCL. Figure 5-3 presents TCE concentrations during the past four years in these four source area monitoring wells. Groundwater contour maps showing the extent of the TCE plume both before and after demonstration system installation are included in the performance reports (NASA, 2005d; NASA, 2006a).

**Table 5-2. Summary of Groundwater Constituents
Detected in the OU-1 Source Area (1996-2005)**

Monitoring Well	Carbon Tetrachloride (µg/L)	TCE (µg/L)	PCE (µg/L)	1,1-DCE (µg/L)	1,2-DCA (µg/L)	Perchlorate (µg/L)
MW-7	<0.5-208	<0.5-39	<0.5-34.7	<0.5-12.4	<0.5-1.4	32.1-13,300
MW-8	0.038-14	0.031-24	0.016-0.5	0.01-0.9	0.064-0.6	0.69-620
MW-13	0.4-27	1-47	0.061-1.4	0.042-1.9	0.03-2.5	0.85-1,410
MW-16	0.082-125	0.046-33	0.031-7.3	0.03-5.3	0.03-2.4	97.2-13,100
MW-24 (Screen 1)	0.038-30	0.036-15	0.005-2.8	0.006-1	0.065-0.8	0.85-4,880
MW-24 (Screen 2)	0.039-58	0.006-4.3	0.005-1.5	0.004-2	0.007-0.5	0.69-700
MW-24 (Screen 3)	0.005-0.5	0.006-0.5	0.005-0.5	0.004-0.5	0.005-0.5	0.66-4
MW-24 (Screen 4)	0.005-0.5	0.006-0.5	0.009-0.5	0.004-0.5	0.007-0.5	0.66-4
MW-24 (Screen 5)	0.005-0.5	0.006-0.5	0.009-0.5	0.004-0.5	0.007-0.5	0.66-4
State MCL	0.5	5	5	6	0.5	—
Notification Level	—	—	—	—	—	6
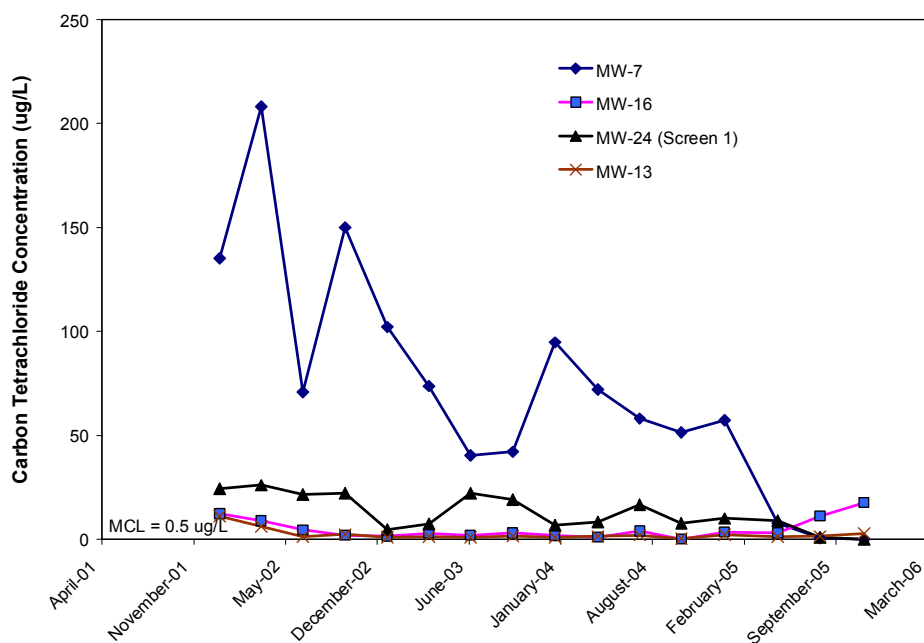
Figure 5-2. Recent Carbon Tetrachloride Concentrations in Source Area Wells
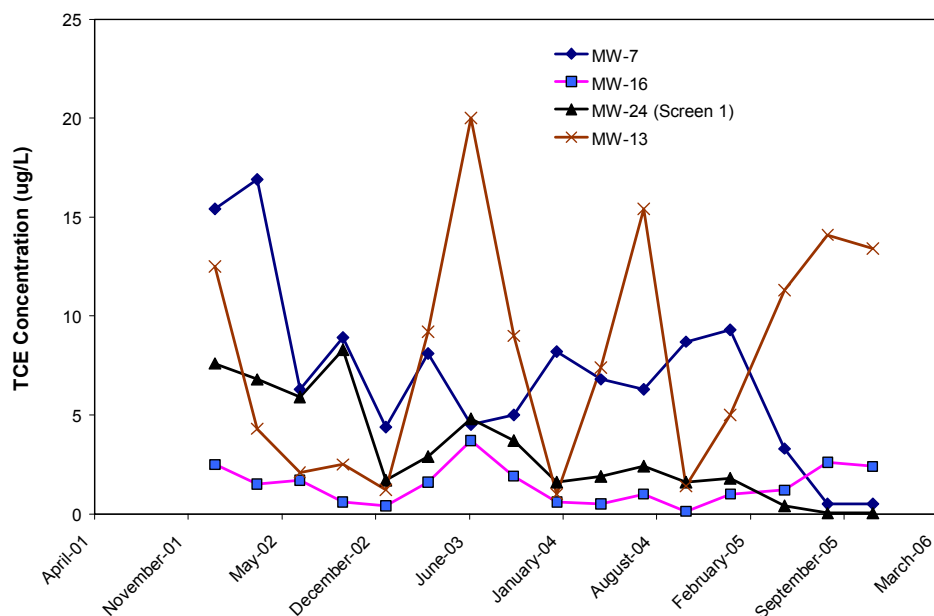
Figure 5-3. Recent TCE Concentrations in Source Area Wells

Tetrachloroethene (PCE)

The highest historical concentration of PCE was detected in source area well MW-7 (34.7 µg/L) as recently as November 2004. However, concentrations in this well fell below the state and federal MCL (5.0 µg/L) after operation of the OU-1 demonstration system began. Figure 5-4 presents PCE concentrations over time for select OU-1 source area wells. Concentrations in MW-16 recently increased above the MCL. Groundwater contour maps showing the extent of the PCE plume both before and after demonstration system installation are included in the performance reports (NASA, 2005d; NASA, 2006a).

1,1-Dichloroethene (1,1-DCE)

1,1-DCE has been detected only in MW-7 above the state MCL of 6.0 µg/L. However, 1,1-DCE has not been detected in this well since operation of the OU-1 demonstration system began. Figure 5-5 illustrates these results.

1,2-Dichloroethane (1,2-DCA)

The state MCL (0.5 µg/L) for 1,2-DCA has not been exceeded since the March 2003 ground-water sampling event (MW-16 at 0.9 µg/L) and the federal MCL (5.0 µg/L) has never been exceeded.

Perchlorate

Concentrations of perchlorate in excess of the notification level (6.0 µg/L) have been reported in samples collected from all source area groundwater monitoring wells, as shown in Figure 5-6.
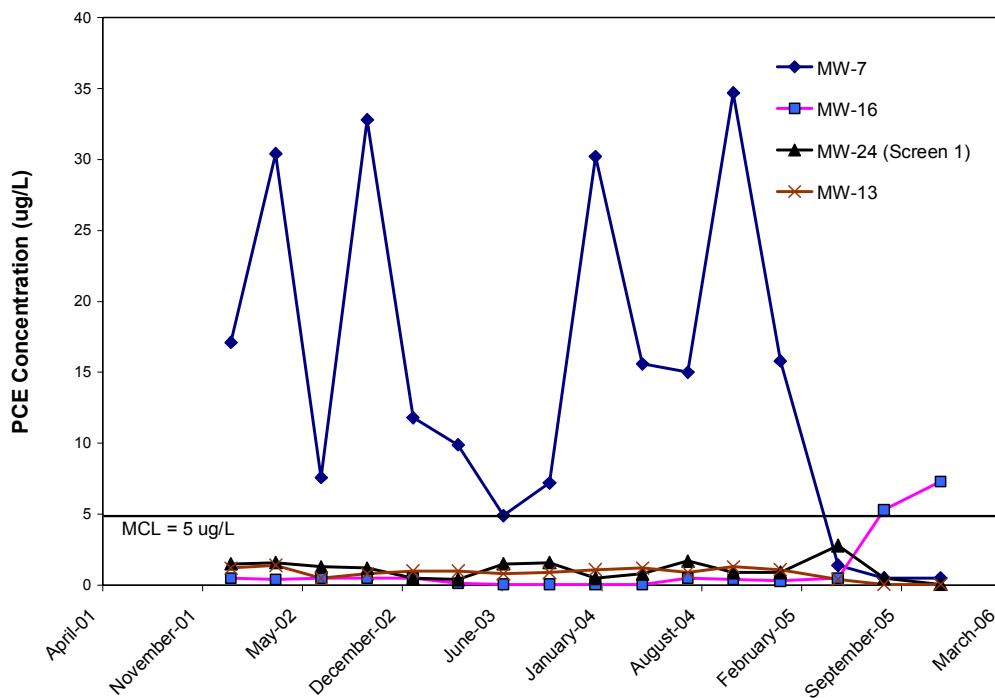
Figure 5-4. Recent PCE Concentrations in Source Area Wells
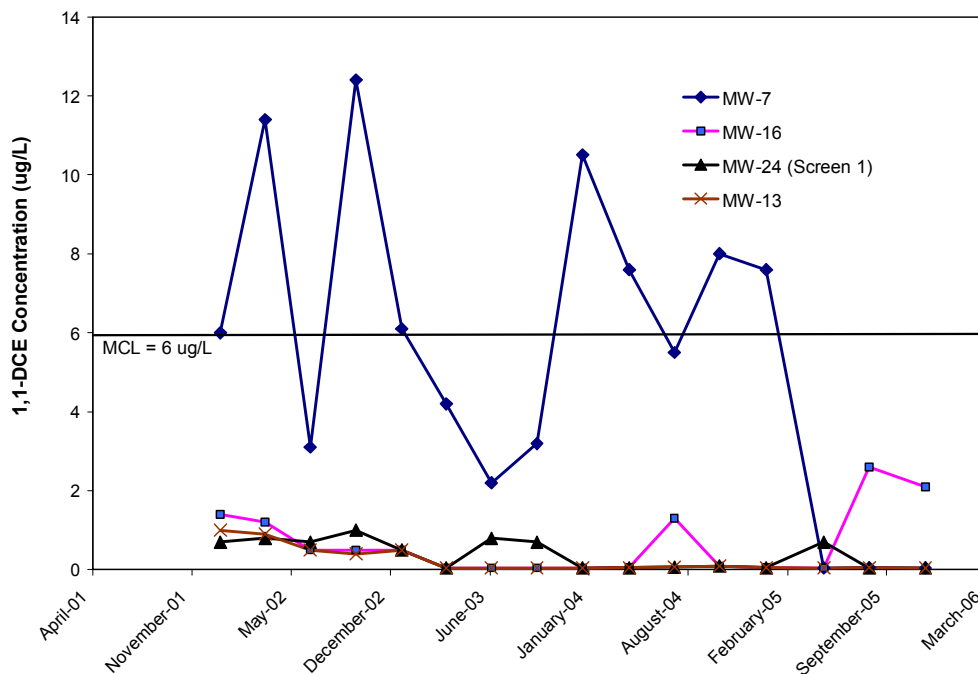
Figure 5-5. Recent 1,1-DCE Concentrations in Source Area Wells

Interim ROD, OU 1 Source Area Groundwater   15   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary
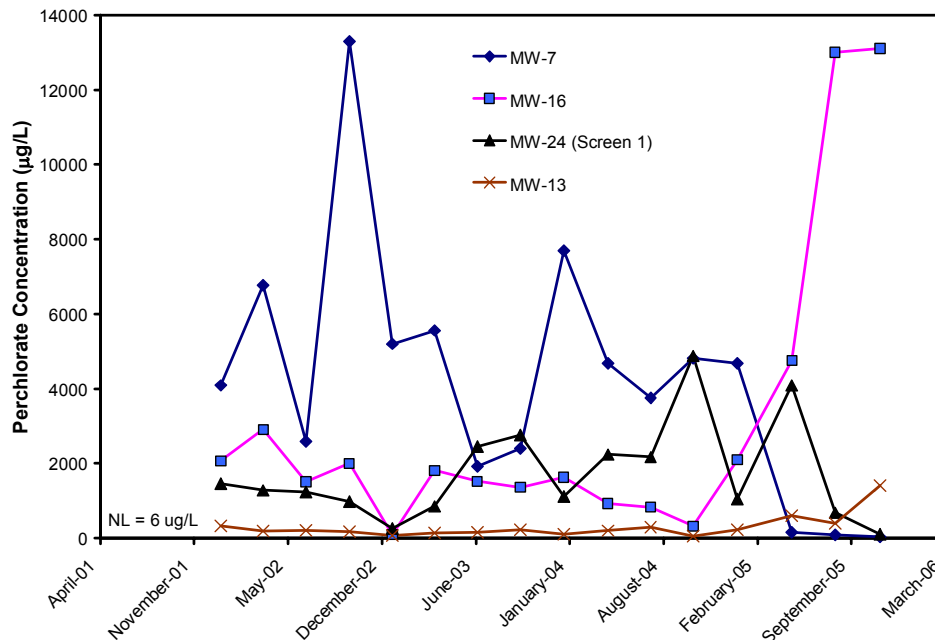
Figure 5-6. Recent Perchlorate Concentrations in Source Area Wells

Concentrations of perchlorate in these wells have generally been unstable over the last few years, which suggest there might be a continuing perchlorate source to groundwater at OU-1. The highest concentrations of perchlorate measured during the past decade were reported in samples collected from wells MW-7 (13,300 μg/L in November 2002) and MW-16 (13,100 μg/L in November 2005). Since startup of the OU-1 demonstration system, perchlorate concentrations have decreased in MW-7 by two orders of magnitude and in MW-24 (Screen 1) by one order of magnitude. However, perchlorate concentrations have increased in MW-13 and MW-16 by an order of magnitude. Groundwater contour maps showing the extent of the TCE plume both before and after demonstration system installation are illustrated in the performance reports (NASA, 2005d; NASA, 2006a).

5.4 Evaluation of the Source Area Groundwater Demonstration Study

The existing demonstration system has two extraction wells, EW-1 screened from 218 to 268 ft bgs and EW-2 screened from 265 to 315 ft bgs (NASA, 2005b). Two injection wells are located approximately 330 ft upgradient to the north. Figure 2-2 illustrates the layout of the demonstration study system.

> Significant reductions in the concentrations of VOCs and perchlorate have been observed in extraction and monitoring wells located within the demonstration study area since initiating operation in February 2005. Therefore, expansion of the system is an appropriate next action.

Extracted carbon tetrachloride concentrations were approximately 37 μg/L after system startup, as illustrated in Figure 5-7. After one year of operation, extracted concentrations have decreased below 1 μg/L in the upper extraction well EW-1 and below 20 μg/L in the deeper extraction well
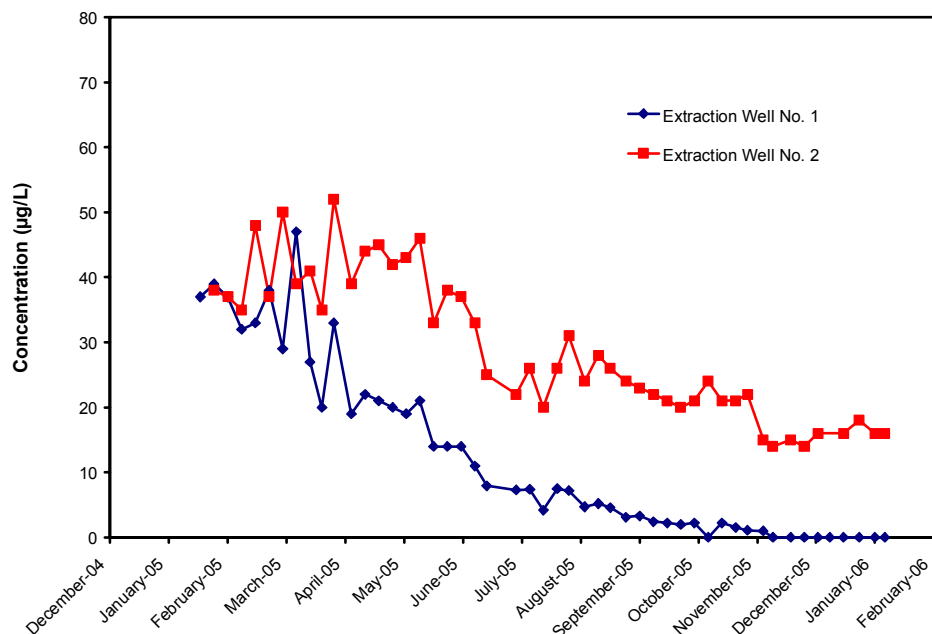
Figure 5-7. Carbon Tetrachloride Concentrations Measured in the Demonstration System Extraction Wells

EW-2. More than 10 lb of carbon tetrachloride have been removed from source area ground-water as of January 2006.

A similar decreasing trend has been observed in extracted perchlorate concentrations, which began with initial concentrations above 2,400 μg/L in EW-1 and above 1,700 μg/L in EW-2. After a year of operation, EW-1 and EW-2 extracted concentrations have decreased nearly an order of magnitude and are approaching asymptotic extraction concentrations above 200 μg/L and 500 μg/L, respectively. Figure 5-8 illustrates these trends. Approximately 413 lb of perchlorate had been removed as of January 2006.

As discussed in Section 5.2, the OU-1 demonstration system has reduced concentrations of a number of constituents to their respective MCLs in source area well MW-7, including carbon tetrachloride, TCE, PCE, and 1,1-DCE, and also has caused perchlorate concentrations to be reduced by two orders of magnitude. Similarly, the demonstration system has reduced carbon tetrachloride concentrations in MW-24 (Screen 1) to the MCL, thereby enabling all VOCs in this well to meet their respective MCLs. In addition, perchlorate concentrations have decreased by an order of magnitude in well MW-24, although concentrations are still above the notification level.
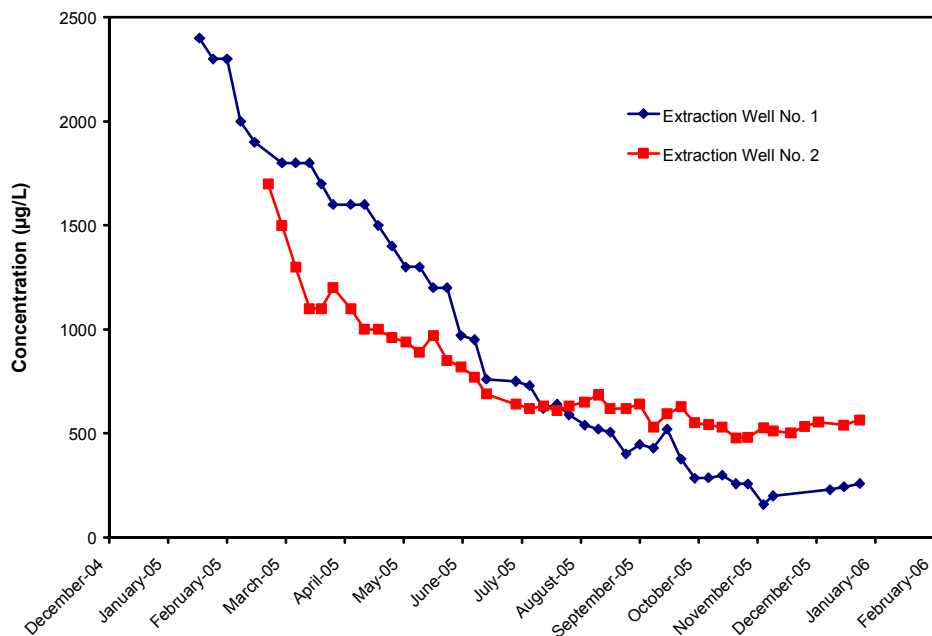
Figure 5-8. Perchlorate Concentrations Measured in the Demonstration System Extraction Wells

However, MCLs have not been met in source area monitoring wells located to the west of the demonstration system. Carbon tetrachloride concentrations still exceed the MCL in MW-13 and MW-16, and TCE concentrations exceed the MCL in MW-13. In addition, perchlorate concentrations also recently increased in each of these wells. Additional groundwater extraction and treatment is required for these source area wells. Hence, installation of additional extraction and injection wells is proposed as part of this ROD (see Figure 2-2). Extraction from these wells will allow additional mass removal.

5.5   Conceptual Site Model

Figure 5-9 is a conceptual site model for the transport of VOCs and perchlorate from the JPL seepage pits to groundwater. A summary of the potential migration pathways and fate and transport processes for chemicals associated with OU-1 is shown in Figure 5-10. The fate and transport characteristics and the potential for downgradient migration of chemicals, particularly carbon tetrachloride, TCE, and perchlorate, were described in detail in the RI Report (FWEC, 1999a). Infiltration and percolation of rainfall, which causes vertical downward flow of VOCs from the vadose zone to groundwater, appears to be the principal transport mechanism by which chemicals are introduced to groundwater at JPL. Soil vapor diffusion and advection also play a role as VOC transport mechanisms within the vadose zone. Thereafter, chemicals are mixed and transported in groundwater via a variety of physical and chemical processes.
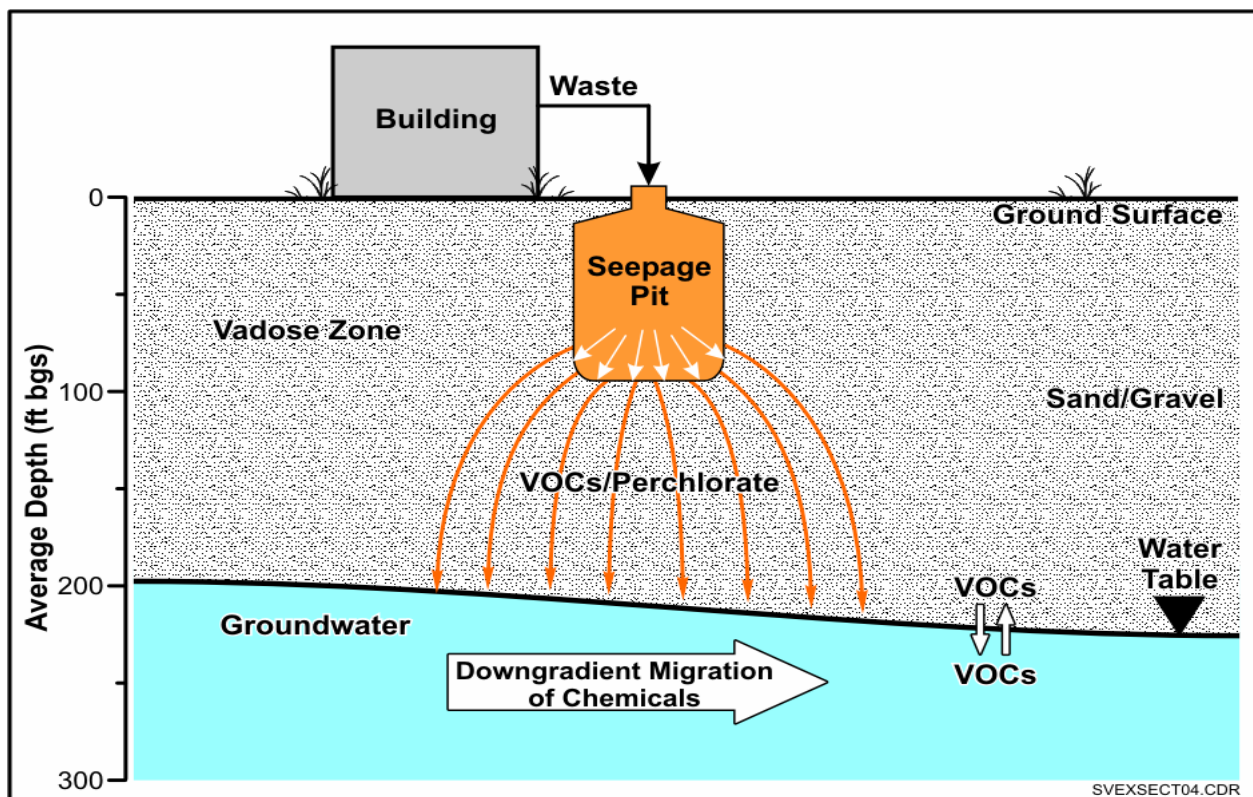
Figure 5-9. Conceptual Site Model for Transport of Chemicals
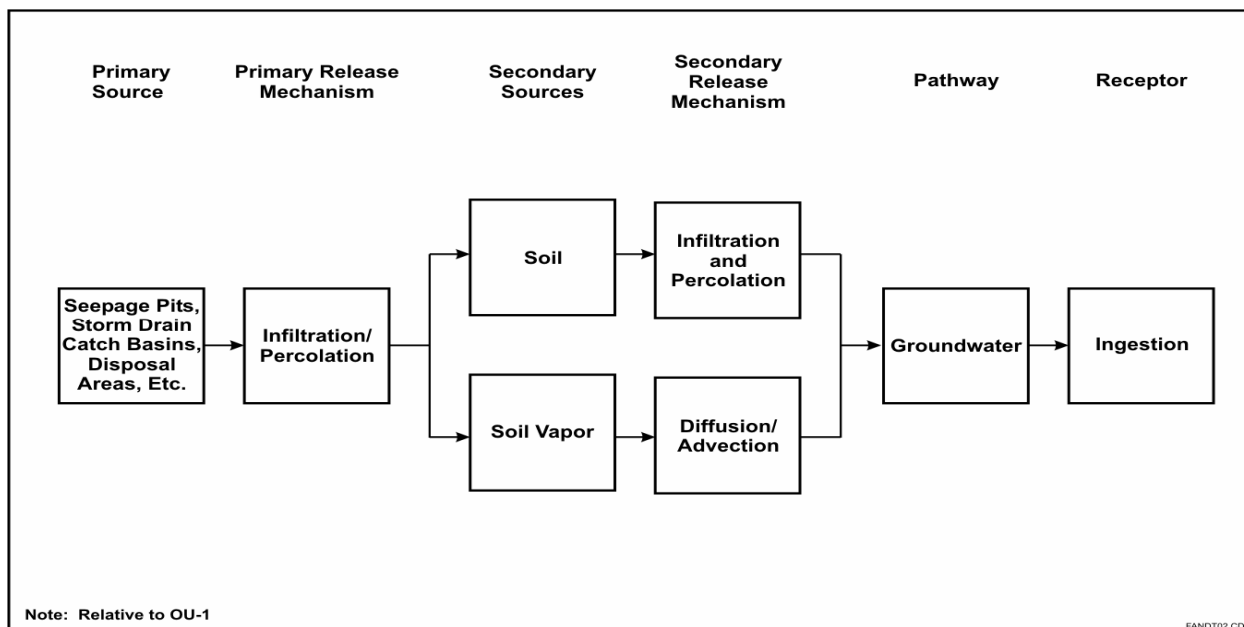
Figure 5-10. Chemical Fate and Transport Conceptual Diagram

Interim ROD, OU 1 Source Area Groundwater   19   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

5.5.1 *Fate and Transport Modeling*

With the RI data and subsequent groundwater monitoring data collected since 1995, the fate and transport of the groundwater constituents at JPL are generally well known. However, fate and transport modeling during the RI was performed as a preliminary evaluation of a scenario. For this model it was assumed that carbon tetrachloride, TCE and perchlorate might migrate further downgradient from the JPL facility, beyond their currently known limits of extent, with natural groundwater gradients present only during periods when the Pasadena and other nearby municipal wells are not operating and inhibiting further downgradient migration. The point source location for constituent migration modeling was chosen as MW-17, aquifer layer 2, because carbon tetrachloride, TCE, and perchlorate were consistently detected above MCLs at this location. The constituent path from MW-17 to MW-20 was selected for the model simulations because MW-20 is downgradient from MW-17 under natural flow conditions and there are no known physical barriers between these two points. Therefore, this path was assumed to provide an appropriate estimate of off-facility migration.

The modeling runs were carried out using SOLUTE™ (Version 4.04) software for each of the three constituents listed above (FWEC, 1999a). In these runs, source concentrations and several input parameters were based on actual facility information or on literature values that were considered to be representative of facility conditions. All input parameters were the same for all simulations with the exception of the initial constituent concentrations, which reflected actual detected values.

Results of the simulations are presented in detail in the RI (FWEC, 1999a). The simulations predicted that with an initial carbon tetrachloride concentration of 6.6 µg/L (maximum detected in MW-17 during the RI), under the defined conditions (no pumping), and with general input parameters based on conservative assumptions, the MCL of 0.5 µg/L would be exceeded in 20 years at MW-20. Similarly, modeling simulations using conservative input assumptions predicted that an initial concentration of 23 µg/L at MW-17 (maximum detected in MW-17 during the RI), would result in a concentration equal to the MCL (5.0 µg/L) at MW-20 after 31 years. With regard to perchlorate, the model indicated that an initial concentration of 55 µg/L at MW-17 (maximum detected in MW-17 during the RI) would result in a concentration at MW-20 equal to the notification level of 18 µg/L, (the DHS notification level at the time the RI fate and transport modeling work was performed) after 40 years.

The results of the fate and transport modeling used actual observed maximum concentrations for carbon tetrachloride, TCE and perchlorate during the RI. The results indicated that even under conservative assumptions, it would take long periods of time for these constituents to migrate downgradient of non-pumping Pasadena and other nearby municipal production wells at concentrations above MCLs or notification levels.

Since that time, the notification level for perchlorate has been reduced to 6 µg/L and the perchlorate concentrations in MW-20 have occasionally exceeded the new notification level. However, during the recent 2005 facility-wide groundwater sampling efforts, perchlorate was not detected in MW-20 (NASA, 2006d).

Interim ROD, OU 1 Source Area Groundwater   20   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

5.5.2 Exposure Pathways

The groundwater at the JPL facility is not extracted for distribution within the facility and workers at the facility do not have access to untreated water from the site. Hypothetically, the exposure mechanisms to untreated groundwater from accessing well water for humans could include ingestion (drinking), dermal (skin) contact, and inhalation of vapors from domestic water sources. For the human health risk assessment (HHRA), potential exposures to chemicals in on-facility groundwater at JPL were quantitatively evaluated for the hypothetical on-facility resident (age-adjusted adult exposed 350 days per year for 70 years) and child resident (6 years). Although a conservative approach was taken for the HHRA, NASA has no intent to use JPL for residential purposes in the foreseeable future. However, NASA based the risk assessments on potential residential use to provide the most conservative and protective results. Direct exposures through ingestion, dermal contact, and inhalation of vapors from water sources were evaluated as exposure pathways to the hypothetical receptors.

For the ecological risk assessment (ERA), an assessment of ecological risks was completed at the JPL facility. The scoping assessment concluded that no groundwater exposure pathways to plants and animals are possible at OU-1. Therefore, it was concluded that no further characterization of ecological risks to plants and animals due to groundwater impact was warranted because there were no complete exposure pathways from groundwater to facility biota. More information on the results of the HHRA and ERA is included in Section 7.0 of this document and in the RI report (FWEC, 1999a).

6.0: CURRENT AND POTENTIAL FUTURE LAND AND RESOURCE USES

JPL is a NASA-owned FFRDC operated by Caltech. It is the federal government's lead center for research and development related to robotic exploration of the solar system. In addition to NASA work, tasks for other federal agencies are conducted at JPL in areas such as remote sensing, astrophysics, and planetary science.

6.1 Land Uses

JPL comprises approximately 176 acres of land. Of these 176 acres, about 156 acres are federally owned. The remaining land is leased for parking from the City of Pasadena and the Flintridge Riding Club. Presently, more than 150 structures and buildings occupy JPL. Total usable building space is approximately 1,330,000 ft^2. The main developed area of JPL is the southern half, which can be divided into two general areas − the northeastern early-developed area and the southwestern later-developed area. Most of the northern half of JPL is not developed because of steeply sloping terrain (see Figure 1-1).

Currently, the northeastern early-developed part of JPL is used for project support, testing, and storage. The southwestern later-developed part is used mostly for administrative, management, laboratory, and project functions. Further development of JPL is constrained because of steeply sloping terrain to the north, the Arroyo Seco to the south and east, and residential development to the west.

Located at the northern boundary of JPL is the Gould Mesa area. This area has widely separated small buildings and is used primarily for antenna testing. The distance between buildings is a result of the terrain and the need to isolate transmitting and receiving equipment. The relatively steep mountainside between Gould Mesa and the developed area at JPL is unpopulated.

The primary land use in the areas surrounding JPL is residential and light commercial. Industrial areas, such as manufacturing, processing, and packaging, are limited. The closest residential properties are those located along the western fence line of JPL. The nearest off-facility build-ings are the Flintridge Riding Club and Fire Camp #2, both located approximately 100 yards from the southern border of JPL. The total number of buildings within 2 miles of JPL is about 2,500, primarily residential and community (e.g., schools, day-care centers, churches). Land use at JPL is not expected to change significantly in the foreseeable future.

6.2 Surface Water and Groundwater Uses

There are no permanent surface water bodies within the boundaries of JPL. The Arroyo Seco Creek intermittently flows through the Arroyo Seco wash to the east of JPL. The entire JPL facility drains, via storm drains and surface runoff, into the Arroyo Seco. In addition, stormwater runoff from parts of La Cañada Flintridge mingles with that of JPL prior to discharge to the Arroyo. Within the Arroyo Seco, a series of surface impoundments are used as surface water collection and spreading basins for groundwater recharge.

Groundwater beneath the Arroyo Seco is a current source of drinking water. The Raymond Basin Watershed, Monk Hill Subarea, where JPL is located, provides an important source of potable water for many communities in the area around JPL. These communities are expected to grow at a modest rate for the foreseeable future and the use of groundwater as drinking water is expected to continue.

Interim ROD, OU 1 Source Area Groundwater   23   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

7.0: SUMMARY OF SITE RISKS (OU-1)

This section of the ROD summarizes the results of the baseline HHRA and the ERA for OU-1. The risk assessment process identifies potential exposure pathways and allows evaluation of the risks to humans and the ecosystem, if no further action were taken at the site.

7.1   Summary of Human Health Risk Assessment

The HHRA was completed to evaluate the potential risks to human health associated with hypothetical exposure to chemicals in untreated groundwater beneath the JPL facility. It is important to note that because groundwater is in a deep aquifer and does not recharge surface water bodies within the area of concern, and because water purveyors treat impacted groundwater before use, there is no complete or direct pathway for exposure to JPL groundwater. Nevertheless, at the request of U.S. EPA and DTSC risk assessors, a conservative hypothetical residential use scenario was evaluated during the RI (FWEC, 1999a) using U.S. EPA risk assessment guidance. It is assumed in the risk assessment that humans use untreated groundwater beneath JPL for potable purposes. Detailed results and methodologies used are presented in the RI (FWEC, 1999a). To ensure that human health is adequately protected, conservative exposure point concentrations and toxicity assumptions were used in estimating potential cancer risks and noncancer hazards.

For carcinogenic compounds, the exposure risk is expressed as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the carcinogen. These risks are expressed in scientific notation (e.g., an excess lifetime cancer risk of 1.0×10^{-6} indicates that an individual experiencing the conservative maximum exposure estimate has a 1 in 1,000,000 chance of developing cancer as a result of site-related exposure). According to the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), 1.0×10^{-6} is defined as the point of departure (i.e., the target level of risk) and the NCP-defined generally acceptable range is 1.0×10^{-6} to 1.0×10^{-4} (U.S. EPA, 1989a).

For noncarcinogenic compounds, risks are evaluated by comparing an exposure level over a specified time period (e.g., lifetime) with a reference dose or level that is not expected to cause any harmful effects. The ratio of the chronic daily intake to the reference dose is called a hazard quotient (HQ). The sum of all of the hazard quotients for each chemical compound is referred to as the hazard index (HI). An HI less than 1.0 indicates that toxic, noncarcinogenic effects from all chemical constituents and exposure routes are unlikely (U.S. EPA, 1989a).

> The only way for the public to come in contact with the groundwater located several hundred feet below the ground surface is through pumping from drinking water production wells located off-facility. These production wells are either shut down or treated prior to water distribution to customers, thus preventing a direct exposure pathway.

The two representative receptors chosen to model risk from hypothetical exposure to untreated groundwater at the JPL site were the residential adult and child. Noncancer and cancer risks were calculated based on a 6-year exposure for the child and a 30-year age-adjusted exposure averaged over 70 years for the adult. Exposure to untreated chemicals of concern in groundwater

was evaluated for ingestion, inhalation, and dermal contact at each JPL monitoring well. It was assumed that the receptors were exposed to the maximum detected or 95 percent upper confidence level (UCL) concentration of chemicals of concern (whichever was higher) in each well for 350 days per year. The exposure scenario is a hypothetical situation that does not reflect realistic current or future land-use scenarios because there are no direct exposure pathways for humans to interact with untreated groundwater in the study area.

The evaluation of noncancer risks for the child receptor show that with the exception of four on-facility monitoring wells (MW-7, -13, -16 and -24), all other monitoring wells produced Hazard Index (HI) values less than 10. Analysis of the HI values based on target organ effects indicates that nine monitoring wells (MW-3, -4, -7, -8, -10, -12, -13, -16, and -24) produced HI values that exceeded the criterion value of 1.0 (see Table 7-1). In these wells, carbon tetrachloride and perchlorate were consistently the predominant chemicals contributing to the excess non-cancer risk.

Table 7-1. Summary of Non Cancer Hazard Index and Cancer Risk for OU-1 Monitoring Wells

OU-1 Well	Hazard Index	Major Chemical Contributor	Risk	Major Chemical Contributor
MW-3	2.1	arsenic, perchlorate	1.1E-04	Arsenic, bromodichloromethane, CCl_4, chloroform
MW-4	8.5	CCl_4, perchlorate	7.7E-05	1,1-DCE, 1,2-DCA, CCl_4, chloroform, TCE
MW-6	<1.0	None	4.0E-06	PCE
MW-7	190	CCl_4, perchlorate	2.2E-03	1,1-DCE, 1,2-DCA, CCl_4, chloroform, Cr^{6+}, PCE, TCE
MW-8	6.3	CCl_4, perchlorate	5.5E-05	CCl_4, chloroform, TCE
MW-10	3.2	perchlorate, nitrate	1.3E-05	Chloroform, PCE, TCE
MW-11	<1	None	1.1E-05	CCl_4, chloroform
MW-12	8.9	CCl_4, perchlorate	1.6E-04	CCl_4, chloroform
MW-13	47	CCl_4, perchlorate	5.5E-04	1,1-DCE, 1,2-DCA, CCl_4, chloroform, Cr^{6+},TCE
MW-14	<1	None	3.1E-06	Chloroform, PCE
MW-16	220	CCl_4, perchlorate	1.4E-03	1,1-DCE, 1,2-DCA, CCl_4, chloroform, Cr^{6+}, PCE, TCE
MW-22	<1	None	3.2E-06	PCE
MW-23	<1	None	5.3E-06	Chloroform, PCE, TCE
MW-24	65	CCl_4, perchlorate	5.2E-04	1,2-DCA, arsenic, CCl_4, chloroform, TCE

Evaluation of cancer risks for JPL OU-1 monitoring wells shows that greater than half of the wells had cancer risk values fall within U.S. EPA's range for acceptable levels of risk of 10^{-6} to 10^{-4} (see Table 7-1). Four wells did not have cancer risks associated with them because no carcinogenic compounds were detected during RI sampling efforts. Six wells had cancer risk values greater than 10^{-4}, of which two wells (MW-7 and MW-16) had cancer risks greater than 10^{-3}. Monitoring well MW-3 slightly exceeded the U.S. EPA acceptable risk range ($>10^{-4}$) and the constituent contributing to the majority of the risk was arsenic. During the RI, arsenic was only consistently detected in the lowest screen of MW-3, below the MCL value of 0.05 mg/L. Arsenic is a naturally-occurring metal and the arsenic detections probably reflect natural concentrations of the analyte and do not represent a human health concern. Three other JPL OU-1 monitoring wells had total cancer risks greater than 10^{-4} (MW-12, MW-13 and MW-24). A variety of chemicals contributed to the total cancer risk value of these wells. Predominant chemical contributors in these wells were as follows: MW-12 (carbon tetrachloride); MW-13 (carbon tetrachloride and hexavalent chromium), and MW-24 (carbon tetrachloride). The two OU-1 wells with the highest total cancer risk were MW-7 (risk = 2.2×10^{-3}) and MW-16 (risk = 1.4×10^{-3}). In these wells, carbon tetrachloride accounted for 91 percent and 86 percent, respectively, of the total risk value. These two wells also have the highest non-cancer risk values (HI values of 190 and 220, respectively).

Theoretical risks to human health predicted by this assessment are likely to be an overestimation of actual risk. In fact, the Agency for Toxic Substances and Disease Registry (ATSDR) has determined that on- and off-facility groundwater at JPL does not pose a present or future public health hazard because wellhead treatment and water blending are used by local water purveyors to meet stringent drinking water standards prior to distribution of the water for public use (ATSDR, 1998). Unlike state and federal guidance that requires exposures to untreated groundwater be evaluated in HHRA, the ATSDR evaluated whether residents are actually being exposed currently, or may possibly be exposed in the future, to chemicals present in groundwater at JPL.

7.2   Summary of Ecological Risk Assessment

An assessment of ecological risks was completed at JPL that qualitatively evaluated potential ecological receptors, chemicals of potential concern (COPCs), and potentially completed exposure pathways for soil, soil vapor, and groundwater. A scoping assessment of ecological risks also was completed to qualitatively evaluate potential ecological receptors, chemicals of potential concern, and potentially complete exposure pathways for groundwater. Groundwater typically underlies the ecological receptors at depths of approximately 200 ft or more, and for this reason, there are not plausible groundwater exposure pathways to plants and animals. It was concluded that no further characterization of ecological risks to plants and animals due to groundwater exposure was warranted as there were no complete exposure pathways (FWEC, 1996).

The assessment used a habitat approach as the basis for identifying potentially complete pathways between areas of impact and specific plant and animal species that may occupy the

facility. Potentially affected habitats within or adjacent to the JPL facility include: urban landscape, chaparral, riparian, wetlands, southern oak woodland, and desert wash. A wide variety of plant and animal species were catalogued during field surveys. The COPCs evaluated for groundwater were the metals and VOCs that were detected in the groundwater during the RI.

The chaparral and southern oak woodland habitats are found only in the San Gabriel Mountains to the north of the JPL facility. Because no impact was known or suspected within the chaparral and southern oak woodland habitats, no potential exposure pathways were identified for these habitats. The riparian, desert wash, and wetland habitats occur off-facility (OU-3) only, and groundwater typically underlies these habitats at depths of approximately 100 ft or more. For this reason, there were no plausible groundwater exposure pathways to plants and animals within riparian, desert wash, or wetland habitats identified during the ERA. The urban landscape habitat is the predominant on-facility JPL habitat. Constituents in groundwater are found at depths between approximately 100 to 250 ft and groundwater does not recharge on-facility surface water bodies. Therefore, no groundwater exposure pathways to plants and animals were identified.

Therefore, it was concluded that no further characterization of ecological risks to plants and animals due to groundwater impact was warranted because there were no complete exposure pathways from groundwater to on-facility biota.

7.3   Basis for Action

The groundwater beneath the JPL facility contains elevated levels of chemicals that represent a continuing source. The basis for the response action is to contain the source of chemicals in groundwater to prevent further migration to receptors (i.e., production wells) located outside the JPL facility boundary, and to reduce the period of performance of actions taken in OU-3.

This response action is part of a phased approach to characterization and cleanup of groundwater affected by chemicals originating from the JPL facility. This action will be followed by a recommendation for a response action in OU-3, and finally by a long-term comprehensive remedial action designed to address all groundwater associated with both OU-1 and OU-3. A phased approach to cleanup is encouraged by Superfund Accelerated Cleanup Model (SACM) (U.S. EPA, 1992a), whereby characterization and performance data collected during initial phases are used to assess restoration potential.

8.0: REMEDIAL ACTION OBJECTIVES

Remedial action objectives (RAOs) in interim decision documents are intended to reduce site risks (by preventing exposure to and further migration of chemicals) and provide additional data to assess the likelihood of restoring groundwater to ARAR or risk-based cleanup levels (i.e., restoration potential). U.S. EPA recommends evaluating restoration potential prior to establishing objectives for the long-term remedy (U.S. EPA, 1996). The response action will be followed by a later, more comprehensive long-term remedy. The RAOs for this response action are as follows:

- Remove chemicals in groundwater and prevent the further spread of VOCs and perchlorate from the groundwater source area.

- Reduce the amount of chemicals distributed in the source area groundwater to improve the effectiveness and efficiency – and reduce costs – of the final cleanup remedy selected for off-facility groundwater.

Interim ROD, OU 1 Source Area Groundwater   28   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

9.0: DESCRIPTION OF ALTERNATIVES

In January 2000, NASA completed a draft Feasibility Study that identified and evaluated various groundwater cleanup alternatives for both the source area and in off-facility areas adjacent to the JPL facility (FWEC, 2000). In addition, a literature review was conducted to assess the development status of various biological, physical, chemical, and thermal treatment technologies used for the removal of perchlorate from groundwater (NASA, 2006e). As part of this effort, NASA also conducted a number of different pilot tests to see which technologies might be the most promising for use at the JPL site. The technologies tested included reverse osmosis, FBR, packed bed reactors, in situ bioremediation, and ion exchange (NASA, 2003a). The pilot testing was completed in 2002 at which time NASA conducted a technical evaluation to determine the best remedial technique for the source area groundwater. Table 9-1 summarizes the advantages and limitations of the different perchlorate treatment technologies evaluated at JPL.

Due to the depth and extent of the chemicals in groundwater as well as the location and density of buildings at JPL, in situ bioremediation is not practical, nor cost-effective, at the JPL facility. Therefore, groundwater must be pumped from the

> The large depth to groundwater limits viable groundwater alternatives at JPL. Based on extensive technology evaluations and testing, two alternatives were selected: (1) no further action; and (2) expansion of the successful demonstration study consisting of groundwater extraction and aboveground treatment.

ground and treated aboveground surface. The best aboveground perchlorate treatment depends on several factors including the perchlorate concentrations that exist, specific site conditions, and other considerations. Two perchlorate treatment processes have been proven at full-scale application at other sites and were effective based on testing at JPL: FBR and ion exchange.

- FBR is cost-effective for relatively high concentrations of perchlorate and at locations where continuous operation can be achieved, such as the source area beneath JPL. The FBR contains carbon particles covered with a coating of bacteria that destroy perchlorate. The primary advantages of this system are the destruction of perchlorate and relatively low operational cost.

- Ion exchange consists of small plastic beads, or resin, in a tank. As the water passes through the tank, perchlorate attaches to the resin. After enough perchlorate attaches to the resin, the resin is removed and sent to a licensed disposal facility, and new resin is added. Ion exchange is the only perchlorate removal technology that has been used for drinking water systems in California and is used at the NASA-funded Lincoln Avenue Water Company system. Ion exchange is more cost-effective at low perchlorate levels, such as those found in groundwater off-facility, and it is more appropriate for operations where the flowrate is varied. Cost estimates obtained for the source area indicate that ion exchange would not be cost-effective, given the relatively high perchlorate concentrations.

**Table 9-1. Matrix of Perchlorate Treatment Technologies Tested at NASA-JPL**

Description	Advantages	Limitations
Fluidized Bed Reactor (FBR): Envirogen conducted a 30-gpm FBR pilot test at JPL in order to evaluate system performance under site-specific conditions and to provide data to size and cost a full-scale system. A 9% solution of ethanol was used as the electron donor, along with small amounts of nitrogen and phosphorous as nutrients to promote microbial growth. No unplanned excursions were experienced during the operation of the FBR pilot test. During the pilot test, biomass film growth was managed manually and no problems were reported with maintaining a stable biomass, or in controlling the bed height or biofilm growth. Over the duration of the test, the influent perchlorate levels averaged 770 µg/L and were treated to nondetect (<4 µg/L) in the effluent.	❑ FBRs have a larger surface area for biomass growth resulting in a smaller footprint and shorter hydraulic residence time compared to PBRs. ❑ Fluidization and continuous biomass control minimizes clogging and/or channeling in the reactor. ❑ The FBR technology has been successfully commercialized (e.g., at least four full-scale systems are currently in operation). ❑ Biological treatment methods are typically less expensive in terms of both capital and operation and maintenance costs compared to physical/chemical processes. ❑ Biological treatment methods typically generate less hazardous waste than physical/chemical processes.	❑ FBRs are reportedly more expensive to build and operate than PBRs. ❑ High recycle rates are required to keep the filter media fluidized and this can increase capital and electricity costs. ❑ Operational problems have been reported in the literature related to bed media loss, bed height control, and the release of biomass into the effluent. ❑ Process is reliable, but performance issues can occur from suboptimal electron donor dosing, pH changes, temperature changes, or other conditions. ❑ Loss of biological activity could interrupt operation for several days. ❑ Use of biological method may be unfavorable for drinking water applications.
Ion Exchange: Calgon Carbon Corporation (Calgon) completed a 5-month pilot test at JPL to test the effectiveness their patented ion exchange process (ISEP^{+TM}) for ClO$_4^-$ removal from groundwater. The ISEP^{+TM} system consists primarily of an ion exchange unit, a ClO$_4$- and nitrate catalytic destruction module (PNDM), a nanofiltration system for sulfate removal from the brine, and a reverse osmosis unit for rinse water treatment. Calgon's ISEP^{+TM} system is configured to operate in a continuous sequence of perchlorate adsorption, regeneration, and rinsing. Continuous operation is made possible by a system of 25 to 30 ion exchange columns that are placed on a rotating carousel. Influent perchlorate concentrations ranged from 250 to 1,200 µg/L and were treated to nondetect levels (<4 µg/L) in the effluent. The PNDM was demonstrated to reduce perchlorate concentrations in the regenerant brine from 60,000 µg/L to <125 µg/L.	❑ Existing technology that has been tested at the pilot and full-scale. ❑ Dedicated commercial vendors and commercially-available resins. ❑ Proven effectiveness at meeting <4 µg/L of perchlorate in effluent. ❑ Physical treatment technologies are more widely accepted for drinking water applications.	❑ Capital and operation and maintenance costs are significantly higher than biological techniques. ❑ Not all resins are highly selective for perchlorate, and other groundwater anions (e.g., nitrate, sulfate) may interfere with its removal. ❑ Brine treatment and disposal issues may limit cost-effectiveness.
Packed Bed Reactors (PBRs): Both lab-scale and field-scale PBR studies have been conducted at JPL by Foster Wheeler. The lab-scale study consisted of PBR column studies to demonstrate the feasibility of perchlorate reduction in both groundwater and simulated reverse osmosis (RO) rejectates. The PBR field-scale system consisted primarily of two bioreactors in series packed with Celite and two bioreactors in series packed with plastic media. Preliminary Phase I effluent data indicate that perchlorate can be reduced from influent levels of 400 µg/L down to nondetect (<4 µg/L). Phase II treatability study results were not available at the time of this review.	❑ PBR pumping requirements and costs are less than FBRs because lower total flowrates and recycle rates can be used without the need for fluidized media. ❑ Biological treatment methods are typically less expensive in terms of both capital and operation and maintenance costs compared to physical/chemical processes. ❑ Biological treatment methods typically generate less hazardous waste than physical/chemical processes.	❑ PBRs appear to be prone to channeling and clogging, and frequent backwashing (at least weekly) may be needed. ❑ Frequent backwashing may impair the ability of the biomass to degrade perchlorate. ❑ Process is reliable, but performance issues can occur from suboptimal electron donor dosing, pH changes, temperature changes, or other conditions. ❑ Loss of biological activity could interrupt operation for several days. ❑ Use of biological method may be unfavorable for drinking water applications.
In Situ Bioremediation (ISB): ISB was evaluated at JPL by ARCADIS during lab and field studies consisting of corn syrup injection to create an in situ anaerobic reactive zone. While the study appeared effective in creating mildly reducing conditions and stimulating some biodegradation of perchlorate, the high flux of groundwater limited the success of the study (ARCADIS, 2004). Due to the depth of groundwater, the variable and generally high groundwater flux, and large size of the groundwater plume at JPL, the primary challenges with ISB are finding effective methods to deliver and distribute sufficient electron donor.	❑ ISB destroys perchlorate in situ, reducing need for aboveground treatment processes. ❑ At some sites, ISB can be configured so that no aboveground treatment and/or disposal of groundwater are needed. ❑ At sites with shallow groundwater and/or a small aerial extent, semipassive or passive delivery methods may involve less capital and operation and maintenance costs compared to ex situ treatment options. ❑ Chlorinated VOCs (e.g., PCE and TCE) may also be degraded with electron donor delivery to the subsurface.	❑ The number of field-scale perchlorate applications conducted to date is limited. ❑ In situ bioremediation is best suited to sites with well-defined source areas and shallow or narrow zones of contamination. ❑ Biofouling can cause significant operation and maintenance issues. ❑ Inefficient donor delivery can lead to little or no in situ biodegradation of perchlorate. ❑ Low pH, high salinity, nitrate, etc. can influence the rate of perchlorate degradation. ❑ ISB can adversely impact groundwater quality (e.g., metals mobilization, sulfide release, methane production).
Continuously Stirred Tank Reactors (CSTRs): A laboratory-scale study was conducted for JPL to evaluate the use of a CSTR for the treatment of RO rejectates. The study demonstrated the rapid development of a perchlorate-reducing culture in a lab-scale CSTR. It was estimated in this study that the CSTR process would be able to reduce perchlorate within a residence time of 1 to 4 hours.	❑ Effectively treats very high levels of perchlorate. ❑ Can be used to reduce perchlorate in high salinity (>2%) wastewaters. ❑ Process is well understood and the system is relatively easy to maintain.	❑ Concentrations above 6,000 mg/L appear to inhibit perchlorate reduction by microbes. ❑ High organic matter present in CSTR effluent may require additional treatment. ❑ High residence times limit the ability to treat high flowrates. ❑ Process is reliable, but performance issues can occur from suboptimal electron donor dosing, pH changes, temperature changes, or other conditions.
Reverse Osmosis (RO): U.S. Filter Corporation conducted a laboratory treatability study to assess the effectiveness of using RO to remove perchlorate from JPL groundwater. Both a thin film composite membrane and a cellulose acetate membrane were evaluated. The results from the thin film composite test were more promising than the cellulose acetate membrane test. In both tests, approximately 80% of the influent stream was recovered as permeate. However, with perchlorate influent levels of 800 µg/L, the thin film membrane achieved 12 to 16 µg/L in the permeate, whereas the acetate membrane contained perchlorate levels as high as 680 µg/L. The rejectate consisted of 20% of the influent stream and contained perchlorate at approximately 3,600 µg/L for the thin film membrane and 1,600 µg/L for the cellulose acetate membrane.	❑ Dedicated commercial vendors. ❑ Physical treatment technologies are more widely accepted for drinking water applications.	❑ Low levels of perchlorate would require multiple passes through RO. ❑ Capital and operation and maintenance costs are significantly higher than biological techniques. ❑ Membrane fouling can cause significant operation and maintenance issues. ❑ Large volume (up to 20%) of waste brine must be treated and/or disposed.

The U.S. EPA has identified air stripping and LGAC as the best technologies to use for aboveground treatment of groundwater containing VOCs, referring to these as "presumptive technologies" (U.S. EPA, 1996). U.S. EPA expects these technologies to be used for removal of VOCs at "all appropriate sites." LGAC treatment is currently in place at JPL and is working effectively as part of the existing source area demonstration treatment system.

Based on earlier studies, NASA installed a demonstration treatment plant (see Figure 9-1) in early 2005, using FBR treatment for perchlorate and LGAC treatment for VOCs (NASA, 2005b). The water is pumped out of the ground, treated, and injected back into the ground approximately 330 ft north of the extraction wells. Figures 9-2 and 9-3 show the layout of the treatment plant, and Figure 9-3 describes the different components of the existing demonstration treatment system.

Construction of the demonstration treatment plant system was completed in early 2005 with design flow operations commencing in March 2005. Operations to date show that the system has been very effective in removing VOCs and destroying perchlorate. More than 400 lb of perchlorate and more than 12 lb of VOCs have been removed since commencing operation of the demonstration study (NASA, 2005d; NASA, 2006a). This system has been successful in its demonstration phase, and expansion of the system has been identified in this ROD as the Preferred Alternative.

For this response action, the Preferred Alternative of expanding the existing demonstration study system is evaluated against the No Further Action (NFA) alternative.
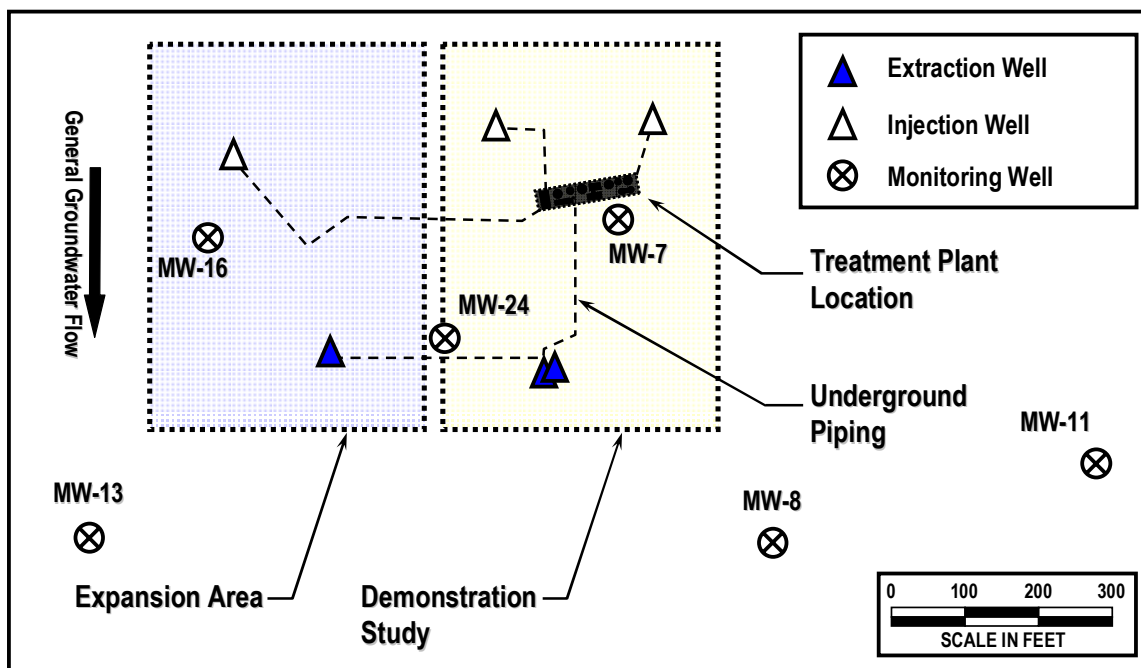
Figure 9-1. Layout of the Existing Demonstration System and the Expansion Area

Figure 9-2. Picture of the Existing Source Area Groundwater Treatment Facility
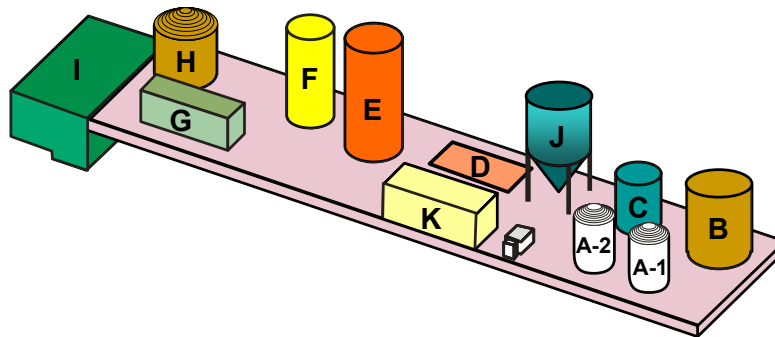
Name	Label	Description
LGAC	A-1, A-2	LGAC vessels to remove VOCs
T-202	B	LGAC backwash water and feed tank
T-201	C	FBR feed tank
FBR Skid	D	Skid with FBR fluidization pumps
FBR	E	Anoxic biological reactor used to remove perchlorate
T-401	F	Aeration tower
F-401	G	Tri-media filter
T-501	H	Treated water tank
T-801	I	Sump for holding F-401's backwash flush water.
Clarifier	J	Condenses solids prior to sanitary sewer discharge
Controls Trailer	K	Trailer contains system controls and on-site laboratory

Figure 9-3. Components of the Demonstration Study Treatment System

9.1   Alternative 1: No Further Action

9.1.1 Description of Remedy Components

The NFA alternative includes no active treatment or containment activities to remediate chemicals in on-facility groundwater at JPL, and no institutional controls to protect the public or the environment from exposure to chemicals in groundwater. However, it does include a groundwater monitoring program currently in place at JPL. As part of the NFA alternative, the results of the monitoring program are used to track concentrations and the extent of chemicals in groundwater beneath JPL over time. The concentrations and extent of chemicals in the groundwater may decrease gradually over time due to chemical or physical transformation, sorption, and/or dilution.

9.1.2 Common Elements and Distinguishing Features

Because groundwater monitoring is the only active component of the NFA alternative, this alternative is not likely to meet chemical-specific ARARs for OU-1, or help the final remedy achieve chemical specific ARARs. The NFA alternative is not likely to be effective over the long term or to meet the RAO for OU-1 in a reasonable timeframe because chemicals in the groundwater are not removed and can continue to migrate to areas off-facility. For a discussion of ARARs for OU-1, see Section 12.2 of this report.

There are no costs for the No Further Action option, other than the existing operation and maintenance (O&M) costs which are part of the existing groundwater monitoring program at OU-1.

9.1.3 Expected Outcomes

The NFA alternative is not a treatment or containment technology and is not expected to reduce the toxicity, mobility, or volume of chemicals of concern at OU-1. Under the NFA alternative, no remediation of OU-1 is planned except that which occurs naturally due to chemical/biological degradation, dispersion, advection, and sorption. The NFA alternative is not expected to prevent further migration of VOCs and perchlorate to areas off-facility, and thus is not expected to meet RAOs for OU-1.

9.2   Alternative 2: Expansion of the Existing Demonstration Treatment System

9.2.1 Description of Remedy Components

Alternative 2 involves expansion of the existing demonstration study system consisting of extraction, treatment and reinjection to remove VOCs and perchlorate from groundwater in the source area. Two different removal processes take place during treatment:

1) **VOC removal.** VOCs are removed from the groundwater by filtration through LGAC. The LGAC is used to reduce carbon tetrachloride, 1,1-TCE,

TCE, PCE, and other VOCs. Once the LGAC is exhausted of absorptive properties, the spent activated carbon is classified as hazardous or non-hazardous waste in accordance with the Code of Federal Regulations (40 CFR 261.31 to 261.33 and 261.21 to 261.24) and the California Code of Regulations (22 CCR) and disposed of accordingly.

2) **Perchlorate removal.** Perchlorate removal is achieved by using a FBR treatment system, which involves a biological process to break down and consume perchlorate from groundwater.

The extraction, treatment, and reinjection system for OU-1 currently consists of a combination of two extraction wells (EW-1 and EW-2) and two reinjection wells (IW-1 and IW-2). Additional extraction and injection wells will be installed and constructed in a manner similar to the existing extraction and reinjection wells at JPL. The extraction, treatment, and reinjection systems will be operated until the criteria for discontinuing operation have been met. Activities associated with the monitoring program will be discontinued once RAOs have been achieved.

9.2.2 Common Elements and Distinguishing Features

Source area groundwater treatment using extraction, treatment and injection will improve the effectiveness and efficiency of the groundwater remedy for OU-3 by significantly reducing chemical mass in groundwater that migrates off-facility. In addition, it will provide a benefit to the final remedy in achieving chemical specific ARARs. For more detail on ARARs, see Section 12.2 of this report.

Extraction, treatment and reinjection are presumptive remedies commonly used to clean up sites similar to OU-1, where VOCs and perchlorate are present in groundwater. VOC treatment technologies are well known (U.S. EPA, 1996). Use of FBR for perchlorate removal from groundwater has a proven track record for effectiveness, reliability, and control based on a review of full-scale operations at other sites. Several full-scale FBR systems for perchlorate removal from groundwater are currently operational. The full-scale performance of FBRs was reviewed based on reports from the 6,000-gallons-per-minute (gpm) Aerojet system, the 50-gpm Long Horn Army Ammunition Plant system, and the 400-gpm Naval Weapons Industrial Reserve Plant McGregor system (NASA, 2006e). In addition, a 150-gpm system currently is operating successfully at JPL. The system has consistently reduced the average influent perchlorate concentration from approximately 1,500 μg/L to <4 μg/L. In addition, no problems were reported with maintaining a stable biomass or in controlling the bed height or biofilm growth (NASA, 2005c; NASA 2005d; NASA, 2006a). Therefore, the treatability study successfully demonstrated that an FBR could be implemented at NASA JPL to treat perchlorate and meet target reinjection levels.

Maximum capital costs for expansion of the existing FBR extraction, treatment, and reinjection demonstration study system are estimated at approximately $1,032,000 (assuming an additional two extraction wells and two injection wells). O&M costs are estimated at approximately $825,000 annually, which does not include the costs for groundwater monitoring associated with either alternative. The extraction, treatment, and reinjection system configuration, sampling

frequencies, and duration used are for cost-estimating and comparison purposes only. A summary of estimated costs is presented in Section 11.3.

9.2.3 Expected Outcomes

The extraction, treatment, and reinjection alternative is expected to permanently reduce the volume of VOCs and perchlorate at OU-1, and to reduce the chemical mass in groundwater that migrates off-facility. Thus, the treatment alternative is expected to meet RAOs for OU-1 and to improve the effectiveness and efficiency of the selected remedy for OU-3. In addition, expansion of the existing demonstration treatment system is not expected to restrict normal activities or future land use at JPL.

10.0: SUMMARY OF COMPARATIVE ANALYSIS OF ALTERNATIVES

NASA evaluated the remedial alternatives for OU-1 in accordance with the nine criteria defined in the NCP (40 CFR Part 300):

- Protection of human health and the environment

- Compliance with ARARs

- Long-term effectiveness and permanence

- Reduction of toxicity, mobility, or volume through treatment

- Short-term effectiveness

- Implementability

- Cost

- State acceptance

- Community acceptance.

These nine evaluation criteria can be categorized into three groups: threshold criteria, primary balancing criteria, and modifying criteria. All threshold criteria must be satisfied in order for a remedial alternative to be eligible for selection. The threshold criteria are protection of human health and the environment and compliance with ARARs. The primary balancing criteria are used to weigh major tradeoffs among alternatives. The primary balancing criteria are long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost. The modifying criteria, state and community acceptance, usually are addressed after public comments are received on the Proposed Plan. At that time, public comments are reviewed with state regulatory agencies to determine if the preferred alternative remains the most appropriate remedial action.

10.1   Comparison of Remedial Alternatives Using Evaluation Criteria

This section uses the nine evaluation criteria to compare and evaluate the remedial action alternatives for OU-1 source area groundwater. Table 10-1 summarizes the screening of the two alternatives for OU-1:

1) Alternative 1, NFA; and

2) Alternative 2, expansion of the existing demonstration treatment system.

10.2   Protection of Human Health and the Environment

Groundwater at the JPL facility is not extracted for distribution within the facility and workers at the facility do not have access to untreated water from the site. The risk assessment in the OU-1/OU-3 RI determined that although there is no complete pathway for exposure to

Table 10-1. Comparison Summary of Remedial Alternatives for OU-1

Criteria	Alternative 1	Alternative 2
Description	• No Further Action	• Expansion of the Existing Demonstration Treatment System
Overall Protection	• Not protective of environment	• Short- and long-term protection of the environment by reducing VOC and perchlorate concentrations
Compliance with ARARs	• Action- and location-specific ARARs are not applicable • Provides no benefit to the final remedy in achieving chemical-specific ARARs	• Complies with action- and location-specific ARARs • Provides benefit to the final remedy in achieving chemical-specific ARARs.
Long-Term Effectiveness and Permanence	• Not effective in long-term • VOCs and perchlorate remain in groundwater and could migrate to off-facility areas	• Effective in long-term • Established technique for removing VOCs and perchlorate from groundwater
Reduction of Toxicity Mobility, or Volume	• No reduction in mobility or volume of VOCs or perchlorate	• Significantly reduces mobility and volume of VOCs and perchlorate through treatment
Short-Term Effectiveness	• No risk to workers, community, or environment	• Does not present substantive risks to on-facility workers or community in short term
Implementability	• Easily implemented	• Technology is proven to be effective, readily available, and easily expandable
Cost	• Approximate cost: $0	• Approximate cost: $8,094,000
Conclusion	• Does not meet criteria	• Preferred Alternative

untreated groundwater from beneath the JPL site, hypothetical exposure to untreated groundwater through mechanisms including ingestion, dermal contact, and inhalation of water vapors could result in unacceptable cancer and non-cancer risks. The scoping assessment of ecological risks concluded that no complete pathway exists for ecological exposure to the untreated groundwater; therefore, no significant ecological risks exist.

Based on these assessments, Alternative 1 (NFA), and Alternative 2 (expansion of the existing demonstration treatment system), are protective of human health because there is no potential for exposure to untreated groundwater. However, if not removed, VOCs and perchlorate may continue to migrate to off-facility areas. Because of this possibility, Alternative 1 is not protective of the groundwater and environment. Under Alternative 2, the reduction of VOC and perchlorate mass in the on-facility groundwater will result in reduced chemical mass migrating to off-facility areas, thereby helping to protect the environment and improving the effectiveness and efficiency of the OU-3 groundwater remedy.

Interim ROD, OU 1 Source Area Groundwater   37   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

10.3 Compliance with Applicable or Relevant and Appropriate Requirements

Section 12.2 of this document contains an evaluation of ARARs that may apply to the OU-1 treatment facility. They include the Resource Conservation and Recovery Act, Safe Drinking Water Act, and policies set by the State Water Resources Control Board and Regional Water Quality Board, among others.

Action- and location-specific ARARs are not applicable to Alternative 1 (NFA). NFA does not provide any benefit to the final remedy in achieving chemical-specific ARARs because groundwater at JPL is not treated. Alternative 2 (expansion of the existing demonstration treatment system) meets all identified ARARs and reduces the migration of VOCs and perchlorate to off-facility areas, providing benefit to the final remedy in meeting chemical-specific ARARs.

10.4 Long-Term Effectiveness and Performance

Alternative 1 (NFA) is not effective over the long term under this alternative, because chemicals in the groundwater can continue to migrate into off-facility areas.

Alternative 2 (expansion of the existing demonstration treatment system) is effective for the long term. The treatment process permanently removes VOCs and perchlorate. The system would be effective over the long term through an overall reduction in the mass and volume of perchlorate and VOCs in the saturated zone that would achieve remediation goals. Alternative 2 is expected to meet the RAO of reducing migration of facility-related chemicals of interest in groundwater, thereby shortening the period of operation of the OU-3 containment/treatment system.

10.5 Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 1 (NFA) is not effective in reducing the toxicity, mobility, or volume of chemicals of concern under this alternative, because chemicals in the groundwater can continue to migrate into off-facility areas.

Alternative 2 reduces the toxicity, mobility, and volume of chemicals of concern. The treatment process used for Alternative 2 destroys perchlorate, eliminating the possibility for subsequent release and exposure. The VOCs that are removed through LGAC treatment are reduced in volume and mobility compared to the untreated groundwater. Waste LGAC would be handled, treated, or disposed of by a licensed commercial waste management firm.

10.6 Short-Term Effectiveness

Alternative 1 (NFA) is not effective over the short term because, under this alternative, chemicals in the groundwater can continue to migrate into off-facility areas.

In general, Alternative 2 is expected to be effective over the short-term. There would be no risk to the community during the expanded system construction and implementation phase, as all of

the components are on the JPL facility. A slight, temporary increase of short-term risk to the environment and workers would occur during construction of the new wells and trenching and the associated generation of waste. However, these risks would be mitigated through safe construction practices and engineering controls. The waste streams generated during operation would be handled, treated, or disposed of by a licensed waste management firm.

10.7 Implementability

Alternative 1 (NFA) is easily implemented. The equipment and methods used for groundwater sampling and analysis are commercially-available and currently in use.

The extraction, treatment and reinjection technologies for removal of VOCs and perchlorate included in Alternative 2 are widely used and have been proven effective during the ongoing treatability study of the OU-1 treatment system. Moreover, the treatment system has already been installed and is capable of expansion.

10.8 Costs

A summary of the present-worth costs associated with the remedial alternatives for OU-1 is presented in Table 10-2. There are no costs associated with Alternative 1.

Table 10-2. Comparison of Cost Estimates for Alternatives 1 and 2

Description	Capital Costs[a]	Annual O&M Costs[a]	Total Cost[a,b]
Alternative 1: NFA			
NFA Cost	—	—	—
Alternative 2: Extraction, Treatment, and Reinjection			
Extraction Treatment Cost	$1,032,000	$825,000	$8,094,000

(a) Costs are estimated to the nearest $1,000. Estimates are within a −30% to +50% range of accuracy.
(b) Total costs are estimated at present-worth value, assuming 15 years operation and 8% annual interest rate.

Costs associated with Alternative 2 include installation and operation of two additional extraction wells and up to two additional reinjection wells. O&M costs for Alternative 2 include operation and maintenance of the FBR system.

10.9 State Acceptance

The state acceptance criterion requires that NASA, as the responsible party, address the state's comments and concerns for each proposed remediation alternative. Comment responses have been accepted by the state. All state agencies have agreed to the proposed remedial Alternatives

1 and 2, and to the selected remedy, Alternative 2. This ROD documents state acceptance of Alternative 2. The DTSC and RWQCB concur with the recommendations of this ROD.

10.10 Community Acceptance

NASA carefully evaluated all public comments taking into consideration information provided by the public and responded to all questions. Part 3 of this ROD documents the comments that NASA received from the public regarding the proposed expansion of the existing OU-1 source area groundwater treatment system and provides NASA's responses to those comments. Although NASA received a number of comments and questions during the public comment period for the Proposed Plan, none of the public stakeholders objected to implementation of the selected remedy.

11.0: THE SELECTED REMEDY

As required by CERCLA and NCP, remedial alternatives were identified and screened based on effectiveness, implementability, and cost. These alternatives were then subject to detailed analysis using the nine criteria described in Section 10.0 of this ROD. Based on the comparative analysis of the remedial alternatives, the selected remedy for addressing OU-1 is Alternative 2, expansion of the existing demonstration treatment system. NASA, U.S. EPA, DTSC, and RWQCB agree with the selection of this alternative for remediation at OU-1.

11.1   Rationale for the Selected Remedy

Based on the evaluation of threshold and primary balancing criteria in Section 10.0, Alternative 2 is the most effective remedial alternative for removal of chemicals of concern from groundwater at JPL. Because of the potential for continued migration of VOCs and perchlorate to off-facility areas, Alternative 1 (NFA) is not protective, and the RAOs for OU-1 cannot be met under this alternative. Alternative 2 will remove VOCs and perchlorate from the groundwater, and thus reduce the migration of VOCs and perchlorate to off-facility areas. The OU-1 expanded treatment system has been running at a rate of 150 gpm since February 2005 and has consistently removed VOCs and perchlorate (NASA 2005c; NASA 2005d; NASA, 2006a).

11.2   Description of the Selected Remedy

Under the selected remedy, VOCs and perchlorate in the groundwater are treated using extraction, treatment, and reinjection methods. New wells will be installed and constructed in a manner similar to the existing OU-1 treatability study wells (EW-1, EW-2, IW-1, and IW-2). One to two new extraction wells and at least one more injection well will be installed as part of the system expansion. In total, the treatment system for OU-1 will consist of up to four extraction wells and four injection wells.

The system expansion will increase the treatment flowrate from approximately 150 gpm to a rate of approximately 350 gpm. The first treatment process is VOC removal; VOCs are removed from the groundwater by filtration through LGAC. The LGAC will be used to reduce carbon tetrachloride, 1,1-DCE, TCE, PCE, and other VOCs. Once exhausted of absorptive properties, the spent activated carbon will be classified as hazardous or non-hazardous waste in accordance with the Code of Federal Regulations (40 CFR 261.31 to 261.33 and 261.21 to 261.24) and the California Code of Regulations (22 CCR) and disposed of accordingly. The second process involved in treatment is the perchlorate removal process. Perchlorate removal will be achieved by using an FBR treatment system, which involves a biological process to break down and remove perchlorate from groundwater.

Potential post-construction refinements may include the following:

- Addition or removal of extraction or injection wells.
- Adjusting the system flowrate.

- Refining ex situ treatment components as influent concentrations change.
- Modifying ex situ treatment chemicals or amendments prior to groundwater reinjection.
- Addition or removal of monitoring wells.

Once operation of the extraction, treatment, and reinjection system is no longer necessary and/or cost-effective to mitigate VOCs and perchlorate migration to off-facility areas at levels of potential concern, the system will be shut down and dismantled.

The selected remedy also includes an ongoing groundwater monitoring program. This program will be used to evaluate the extraction, treatment, and reinjection system effectiveness and remedial progress. The groundwater monitoring program will be terminated upon achieving the RAO.

11.3 Estimated Remedy Costs

Table 11-1 presents the estimated capital costs for the full-scale extraction, treatment and reinjection system at OU-1. The term capital cost refers to the funds required to cover the initial non-recurring costs associated with purchasing and installing the technology to the point where it is ready for its intended use. The capital cost estimate for the extraction, treatment, and reinjection system at JPL OU-1 is based on the installation of a maximum of four extraction wells and four reinjection wells. Costs associated with the installation of the extraction, treatment, and reinjection wells include drilling expenses, waste disposal, well materials, and other miscellaneous expenses. The design and construction management costs also are included as part of the capital cost.

**Table 11-1. Estimate of Capital Costs for Expansion of the
Existing Demonstration Treatment System**

Description	Total Cost
Well Installation	$480,000
Engineering & Submittals	$24,000
Capital Equipment	$18,000
System Installation	$280,000
Project Management/Design	$230,000
Total	**$1,032,000**

The O&M costs of a technology are the recurring or periodic costs incurred during the operating life of the system. The OU-1 O&M costs include labor, equipment rental, carbon replacement costs, and other expenses. Table 11-2 presents the annual O&M costs for extraction treatment and reinjection at OU-1. Groundwater monitoring costs were not included as part of the remedy operation costs.

Table 11-2. Estimate of Annual Operation and Maintenance Costs for OU-1

Field Program	Quantity	Unit	Unit Cost	Total Cost
On-site Labor	1	Per Year	$113,800	$113,800
Chemicals	1	Lot	$128,202	$128,202
Bag Filters	5	Case of 50	$213.50	$1,068
Carbon	1	Per Year	$52,800	$52,800
Electricity	12	Per Month	$3,000	$36,000
Laboratory-Performance	12	Per Month	$12,043	$144,516
Laboratory- Sanitary Sewer	24	Per Event	$1051.75	$25,242
Other Rental/Disposal	1	Lot	$39,800	$39,800
Well rehabilitation	2	Per Year	$25,500	$51,000
Reporting/Project Management	1	Per Year	$232,600	$232,600
Annual O&M Cost				**$825,028**

The total present worth for expansion of the existing demonstration treatment system is estimated to be $5,046,000 based on the capital costs and the annual OU-1 O&M costs incurred over the life of the project. The amount does not include groundwater monitoring costs. The term "present worth" represents the amount of money or principal needed today to cover the costs over the lifetime of the remediation project given a certain interest rate. This present-worth cost estimate was based on the following simplifying assumptions:

- Implementation time for the selected remedy is 15 years.

- Interest rate of 8%.

The OU-1 system configuration, sampling frequencies, and project duration listed in the proceeding sections are conservative for cost-estimating purposes only, and may vary during remedy implementation.

11.4 Expected Outcomes of the Selected Remedy

The response action for OU-1 is intended to provide source treatment and containment to prevent migration of chemicals off-facility and reduce clean up times for OU-3. JPL is located within the Raymond Basin Watershed, which is a current source of drinking water.

It is anticipated that the response action will help to reduce OU-3 groundwater treatment costs and help restore aquifer water quality. Performance objectives have been established to evaluate system effectiveness until the final remedy is in place. The performance of the system will be evaluated and optimized on a continuing basis and the information regarding the amount of VOCs and perchlorate removed will be reported to the regulatory agencies as needed to effectively evaluate system performance objectives. The performance objectives include the following:

- Reduction of overall VOC and perchlorate concentrations within the groundwater monitoring wells and extraction wells compared to baseline levels.

- Asymptotic mass removal achieved after appropriate system optimization. Asymptotic conditions will have been reached when the upper limb of the cumulative mass removal curve approaches zero.

- Operate only as long as cost-effective. The OU-1 source area groundwater treatment system will no longer be cost-effective when operating costs per unit of VOC and perchlorate mass removed from the groundwater indicate that the additional cost of continuing to operate the system is not warranted and/or when shutdown of the OU-1 system is not anticipated to significantly increase the cost of the OU-3 groundwater remedy or significantly prolong the time to achieve groundwater cleanup.

The existing groundwater monitoring network will be evaluated during the remedial design phase to determine if sufficient coverage is available to monitor changes in the lateral and vertical distribution of VOCs and perchlorate, as well as the effectiveness of cleanup. Additional groundwater monitoring wells will be installed as necessary to monitor effectiveness of the response action.

After the performance objectives have been achieved, the OU-1 system may be idled and groundwater monitoring will continue to evaluate rebound. In addition, the system will be idled if MCLs are achieved in the source area (see Section 12.2). If significant rebound occurs, the OU-1 system will be reinitiated; otherwise the system will be permanently shut down and dismantled. When performance objectives have been achieved, NASA will request shutdown of the OU-1 system. NASA will shut down the OU-1 system once approval has been granted by the U.S. EPA, DTSC and RWQCB.

Minimal environmental impacts are expected from OU-1 response action implementation. Groundwater treatment will have no adverse impacts on threatened or endangered species, cultural resources, floodplains, or wetlands. NASA expects no adverse human health impacts from this CERCLA action to occur in any off-facility community, including minority and low-income communities. With system implementation, increases in JPL traffic will be minimal and consist of transportation of equipment and supplies to and from the JPL facility, resulting in insignificant transportation impacts. There will be no measurable impact on the local economy as a result of system implementation, and thus, no socioeconomic impacts are anticipated. Also, there will be no irreversible and irretrievable commitment of resources and the cost of remediation is justified to protect the existing source of drinking water.

Additional information regarding the anticipated socioeconomic, transportation, natural resources, and environmental justice impacts associated with the implementation of OU-1 response action are discussed in the NEPA Values Assessment (NASA, 2006c).

Interim ROD, OU 1 Source Area Groundwater   44   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

12.0: STATUTORY DETERMINATIONS

NASA must undertake remedial actions at this CERCLA site to achieve protection of human health and the environment. In addition, the selected remedy for this site must meet applicable or relevant and appropriate environmental standards as established under federal and state environmental laws, unless a statutory waiver is justified. The selected remedy must also be cost-effective and use permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable. Finally, the remedy should also employ treatment to permanently and significantly reduce the volume, toxicity, or mobility of chemicals in the source area groundwater. This section provides a brief description of how the selected remedy, expansion of the existing demonstration system, satisfies the statutory requirements of CERCLA.

12.1   Protection of Human Health and the Environment

Groundwater at the JPL facility is not extracted for distribution within the facility and workers at the facility do not have access to untreated water from the site. Because there is no complete pathway for exposure to untreated groundwater from beneath the JPL site, there is currently no human health risk associated with OU-1. However, if not removed, VOCs and perchlorate may continue to migrate to off-facility areas. Because of this possibility, Alternative 1 (NFA) is not protective of the groundwater and environment. Under Alternative 2, the reduction of VOC and perchlorate mass in the on-facility groundwater will result in reduced chemical mass migrating to off-facility areas, thereby helping to protect the environment and improving the effectiveness and efficiency of the OU-3 groundwater remedy. Alternative 2 does generate concentrated VOC waste in the form of spent carbon; however, this waste stream is easily managed and can be disposed of safely.

12.2   Compliance with Applicable or Relevant and Appropriate Requirements

Compliance with ARARs addresses whether a remedial action alternative meets all pertinent federal and state environmental statutes and requirements. An alternative must comply with ARARs or be covered by a waiver to be acceptable. This section discusses ARARs associated with the Safe Drinking Water Act (SDWA), the Resource Conservation and Recovery Act (RCRA), and various resolutions set forth by the state and the RWQCB. However, in accordance with U.S. EPA guidance, only those requirements that are ARARs to the limited-scope interim action are discussed (U.S. EPA, 1999). An interim action must comply with ARARs triggered by the action and location (e.g., regulations concerning disposal and reinjection). However, an interim action does not need to comply with chemical-specific ARARs that will be addressed by the final remedy (e.g., attaining aquifer cleanup to certain levels).

To implement the expanded treatment system, various regulatory issues and legal considerations must be examined in regard to the injection of treated groundwater. Because the JPL is on the

National Priorities List (NPL), the site is subject to the provisions of CERCLA as amended by SARA. As such, federal regulations and policy governing reinjection of water into the subsurface will be adhered to, in conjunction with complying with the substantive requirements of state regulations and policy (U.S. EPA, 1992b). Legal considerations of reinjection must also be examined because the JPL facility is located in the adjudicated Raymond Basin Watershed.

12.2.1 Federal Regulations and Policy

Safe Drinking Water Act − Federal MCLs developed by U.S. EPA under the SDWA are potential relevant and appropriate requirements for aquifers. The point of compliance for MCLs under the SDWA is at the tap. Therefore, the MCLs are not "applicable" ARARs for NASA sites. However, MCLs are generally considered relevant and appropriate as remediation goals for current or potential drinking water sources, and therefore are potential chemical-specific federal ARARs for final groundwater remedial actions under CERCLA. Because this is an Interim ROD, establishing cleanup goals for the aquifer is not part of this response action. Cleanup goals for the aquifer will be addressed as part of the final remedy for groundwater. However, the system will be idled if MCLs are achieved within the source zone prior to implementing the final remedy for groundwater (see Section 11.4).

Resource Conservation and Recovery Act − Section 3020 of RCRA applies to the underground injection in the context of RCRA and CERCLA cleanups. RCRA section 3020(a) bans underground injection into or above a geologic formation that contains an underground source of drinking water. However, RCRA section 3020(b) provides an exemption from that ban if certain conditions are met (U.S. EPA, 2002). These conditions include the following:

- The reinjection is part of a response action under Section 104 or 106 of CERCLA, or part of RCRA corrective action intended for site cleanup;

- The groundwater is treated to substantially reduce chemicals prior to such reinjection; and

- The cleanup will, upon completion, be protective of human health and the environment.

The second point above means that treatment must occur before reinjection; however, the substantial reduction of the chemicals in the groundwater can occur either before or after reinjection of the groundwater (U.S. EPA, 2000).

The applicability of RCRA land disposal restrictions (LDRs) to groundwater reinjection performed during an RCRA corrective action or CERCLA response action is also a consideration (see RCRA sections 3004 (f), (g), and (m), and 40 CFR Parts 148 and 268). Groundwater undergoing reinjection may contain regulated chemicals; thus, the issue could be raised as to whether reinjection of groundwater should meet treatment standards identified as best demonstrated available technology (BDAT). An interpretation of the applicability of the RCRA LDRs is provided in an EPA memorandum titled "Applicability of Land Disposal Restrictions to RCRA and CERCLA Ground Water Treatment Reinjection" (U.S. EPA, 1989b). This memorandum

explains that even though the LDR provisions address the same activity as RCRA section 3020, U.S. EPA interprets the provisions of RCRA section 3020 to be applicable instead of LDR provisions (U.S. EPA, 1989b).

Another potential issue is whether LDR treatment standards are relevant and appropriate for treated groundwater that is reinjected as part of a CERCLA response action. The U.S. EPA believes that the ultimate purpose of treatment is to restore the groundwater to drinking water conditions; thus, standards that have been developed to establish drinking water quality levels (e.g., MCLs) are to be used. Therefore, promulgated drinking water standards should be used where available. If no promulgated drinking water standard exists, then relevant and appropriate requirements such as health-based standards or LDR treatment standards should be used (U.S. EPA, 1989b).

RCRA Hazardous Waste Identification Criteria − These criteria (40 CFR 261) are promulgated by the federal government to define RCRA hazardous waste. An RCRA hazardous waste is a waste that appears on one of the four hazardous wastes lists (F-list, K-list, P-list, or U-list), or exhibits at least one of four characteristics (of hazardous waste) − ignitability, corrosivity, reactivity, or toxicity. Hazardous waste is regulated under RCRA Subtitle C. This requirement may apply to the disposal of LGAC media and other process waste. The spent media will be characterized in accordance with RCRA and will be disposed of accordingly.

12.2.2 State Regulations and Policy

California Safe Drinking Water Act and State MCLs – California has established standards for sources of public drinking water, under the California Safe Drinking Water Act of 1976 (H&SC Section 4010.1 and 4026[c]) and state MCLs for organic chemicals are set forth in CCR Title 22, Section 64444. Some state MCLs are more stringent than the corresponding federal MCLs. In these instances, the more stringent state MCLs are applicable to the remedial action at JPL. NASA has determined that the substantive provisions of the standards in CCR Title 22, Section 64444 are relevant and appropriate to the final remedy for groundwater because VOCs will be remediated to a level expected to protect groundwater quality. Since this is an Interim ROD, establishing cleanup goals for the aquifer is not part of this response action. Cleanup goals for the aquifer will be addressed as part of the final remedy for groundwater. However, the system will be idled if MCLs are achieved within the source zone prior to implementing the final remedy for groundwater (see Section 11.4).

General Waste Discharge Requirements – General waste discharge requirements (WDRs) associated with groundwater reinjection during remedial activities are provided by the RWQCB Los Angeles Region in Order No. R4-2005-0030, *General Waste Discharge Requirements for Groundwater Remediation at Petroleum Hydrocarbon Fuel and/or Volatile Organic Compound Impacted Sites* (RWQCB, 2005). These general WDRs are applicable to in situ groundwater remediation or the extraction of groundwater with aboveground treatment and reinjection of treated groundwater to the same aquifer zone. The requirements contained in Order No. R4-2005-0030 are consistent with all water quality control policies, plans, and regulations in the California Water Code (CWC) and the revised Water Quality Control Plan (Basin Plan) for the Los Angeles Region (RWQCB, 1994). The general WDRs are intended to protect and maintain

Interim ROD, OU 1 Source Area Groundwater   47   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

the existing beneficial uses of the receiving groundwater (RWQCB, 2005) and are consistent with the anti-degradation provisions of State Water Resources Control Board Resolution No. 68-16.

RWQCB Order No. R4-2005-0030 requires that groundwater reinjection shall not adversely impact the receiving groundwater in terms of water quality and chemical concentrations at a "compliance point, downgradient and outside the application area." The application area at JPL is the same as the source zone (i.e., the 8-acre by 100-ft thick portion of the aquifer containing elevated levels of VOCs and perchlorate). Impacts to the water quality and chemical concentrations of the receiving groundwater will be evaluated as part of NASA's groundwater monitoring program at JPL based on analytical results from samples collected from monitoring wells located inside the application area (i.e., source area), wells located outside the source area but still within the plume of target chemicals, and wells located outside the current plume of target chemicals. Groundwater will be treated prior to reinjection (see Section 9.0) to reduce concentrations of target chemicals. All reinjected water will be treated to concentrations cleaner than the receiving water. The electron donor to be used will be the same as, or similar in nature to, carbon sources/electron donors listed in RWQCB Order No. R4-2005-0030, Provision A(c)(4). This action will comply with the substantive requirements associated with groundwater reinjection in the general WDRs and State Water Resources Control Board Resolution 68-16.

Non-RCRA (California) Hazardous Waste Identification Criteria − These criteria (CCR Title 22 Section 66261.24) are promulgated by the State of California to define non-RCRA (California) hazardous waste. A non-RCRA (California) hazardous waste can be identified as a listed waste, or as a waste that exhibits hazardous characteristics − ignitability, corrosivity, reactivity, and toxicity. This requirement may apply to the disposal of LGAC media and other process waste. The spent media will be characterized in accordance with California hazardous waste requirements and will be disposed of accordingly.

12.2.3 Legal Considerations

JPL is located in the Monk Hill Subarea of the Raymond Basin. In 1944, the Superior Court of California approved the Raymond Basin Judgment, which adjudicated the rights to groundwater production to preserve the safe yield of the groundwater basin. Adjudication refers to the practice of land owners and other parties allowing the courts to settle disputes over how much groundwater can rightfully be extracted. The courts determine an equitable distribution of water that will be available for extraction each year. In these adjudicated groundwater basins, the courts appoint a Watermaster to administer the court judgment. The Raymond Basin Management Board, made up of representatives of the water purveyors, oversees the management and protection of the Raymond Basin. A total of six Raymond Basin water purveyors operate wells within four miles of JPL.

Because the expanded treatability study includes the extraction of groundwater and NASA does not have water rights under the Raymond Basin Judgment, extracted groundwater will be reinjected into the same aquifer. NASA will coordinate with the Raymond Basin Management Board regarding specific reporting requirements associated with reinjection.

Alternative 1 (NFA) does not meet chemical-specific ARARs because groundwater at JPL is not protected. Alternative 2 (expansion of the existing demonstration treatment system) meets all identified ARARs and reduces the migration of VOCs and perchlorate to off-facility areas.

12.2.4 Other Applicable Requirements

CERCLA Offsite Rule − The off-site rule (40 CFR 300.440) applies to any response action involving the off-site transfer of CERCLA wastes. Therefore, the off-site rule will apply to disposal of spent LGAC and other process waste associated with the source area treatment system. The purpose of the off-site rule is to avoid having CERCLA wastes from response actions authorized or funded under CERCLA contribute to present or future environmental problems by directing these wastes to management units determined to be environmentally sound (preamble to final Off-Site Rule, 58 *Federal Register* 49200, 49201, Sept. 22, 1993). All waste will therefore be disposed of at a facility that is permitted to accept waste from the CERCLA site.

12.3   Cost-Effectiveness

Cost-effectiveness is determined by comparing the cost of all alternatives being considered with their overall effectiveness to determine whether costs are proportional to the effectiveness achieved. The overall effectiveness of a remedial alternative is determined by evaluating (1) long-term effectiveness and permanence, (2) reduction in toxicity, mobility, or volume through treatment, and (3) short-term effectiveness. Table 12-1 presents a comparison of costs and effectiveness of Alternative 1 (NFA) and Alternative 2, for OU-1.

Alternative 1 is not effective over the long term because, under this alternative, VOCs and perchlorate in the groundwater can continue to migrate into off-facility areas. Alternative 2 is effective over the long term because the process permanently removes VOCs and perchlorate from the groundwater and existing and future risks to off-facility groundwater are reduced. After remediation is complete, residual VOCs and perchlorate are not expected to further impact groundwater.

Alternative 1 (NFA) is not a treatment technology and does not reduce the toxicity, mobility, or volume of VOCs or perchlorate in the groundwater at OU-1. Alternative 2 (expansion of the existing demonstration treatment system) is a remedy that permanently and irreversibly removes VOCs and perchlorate from groundwater. Thus, Alternative 2 reduces the volume and mobility of VOCs and perchlorate in the groundwater at OU-1.

Interim ROD, OU 1 Source Area Groundwater   49   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

Table 12-1. Comparison of Costs and Effectiveness of Alternatives for OU-1

Alternative	Present-Worth Cost	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-Term Effectiveness
Alternative 1 (NFA)	$0	• Not effective over the long term • VOCs and perchlorate can continue to migrate into unaffected groundwater	• Not a treatment technology • Does not reduce toxicity, mobility, or volume of VOCs and perchlorate in groundwater	• No short-term effects on workers, public, or the environment
Alternative 2 (Expansion of the Existing Demonstration Treatment System)	$8,094,000	• Effective over the long term • VOCs and perchlorate permanently removed from groundwater	• Presumptive remedy • Permanently removes VOCs and perchlorate from groundwater	• Insignificant short-term effects on workers, the public, and the environment

Alternative 1 does not include remedial action. Because this alternative does not require construction or installation of equipment on facility, potential short-term effects to workers, the public, and the environment are minimal. Alternative 2 presents minimal risk to workers, the public, and the environment. Groundwater extraction, treatment and reinjection systems are designed so that extraction, injection wells and associated piping are under constant monitoring. The VOCs and perchlorate in the extracted groundwater are removed by an aboveground treatment system, in accordance with state and local regulations. The potential short-term effects to workers, the public, and the environment are expected to be minimal during the expansion and operation of the treatment system.

The estimated present-worth cost of Alternative 1 is $0. Because Alternative 1 does not reduce the toxicity, mobility, or volume of VOCs and perchlorate at OU-1, it is not effective in the long term, and, therefore, is not a cost-effective alternative.

The estimated present-worth cost of Alternative 2 is $8,094,000. Because Alternative 2 permanently reduces the volume of VOCs and perchlorate at OU-1, and thus reduces future risks to off-facility groundwater, it is cost-effective in the long term. The operation of OU-1 also will help to decrease the cost of remediation efforts at OU-3.

NASA and the regulatory authorities agree that the costs associated with extraction treatment and reinjection are justified because the preferred action reduces and removes VOCs and perchlorate from groundwater at JPL OU-1 and reduces the potential for continued migration of untreated groundwater to off-facility areas. Thus, groundwater beneath JPL is protected, as required under both NCP (40 CFR Section 300.430(e)(2)(B)) and State of California regulations for the beneficial use of groundwater.

12.4   Use of Permanent Solutions and Alternative Treatment Technologies

Alternative 1 (NFA) does not meet chemical-specific ARARs and cannot meet the RAO for OU-1 because, under this alternative, VOCs and perchlorate are left in place at OU-1, and unaffected groundwater beneath and surrounding JPL is not protected. In addition, Alternative 1 is not a treatment technology, does not reduce the toxicity, mobility, or volume of chemicals of concern at OU-1, and is not effective over the long term, because VOCs and perchlorate are left in place with the potential to migrate to off-facility groundwater.

Alternative 2 (expansion of the existing demonstration treatment system), the selected remedy, is a presumptive remedy that permanently removes VOCs and perchlorate from the groundwater, thus reducing the volume of chemicals of concern at OU-1. This alternative is effective over the long term, is protective of human health and the environment, and can meet all ARARs.

12.5   Preference for Treatment as a Principal Element

Expansion of the existing demonstration treatment system can permanently remove VOCs and perchlorate from the groundwater at OU-1, and thus reduce their volume and mobility. Expansion of the existing demonstration treatment system meets the CERCLA preference for treatment as a principal element.

12.6   Five-Year Review Requirements

NASA intends to remove VOCs and perchlorate in the groundwater at JPL to prevent further migration of VOCs and perchlorate to unaffected groundwater used for drinking water. A review will be conducted every five years to ensure that the remedy continues to provide adequate protection of human health and the environment. This review is required five years after finalizing the first ROD for the site. The ROD for OU-2 was signed in September 2002 (See, 42 USC 9621(c)); hence, the first review will take place in 2007.

13.0: DOCUMENTATION OF SIGNIFICANT CHANGES

The Proposed Plan identified Alternative 2 (expansion of the existing demonstration treatment system) as the Preferred Alternative for remediation of groundwater chemicals of concern at JPL (OU-1). NASA reviewed all written and verbal comments submitted during the public comment period, and no changes to the preferred alternative and no new alternatives that NASA had not previously considered were suggested by the public during the public comment period. It was determined by NASA, U.S. EPA, DTSC, and RWQCB that no significant changes to the remedy, as originally identified in the Proposed Plan, were necessary or appropriate.

14.0: REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR). 1998. *Public Health for Jet Population Laboratory.* U.S. Department of Health and Human Services.

ARCADIS G&M, Inc, 2004. *Pilot Study of an In Situ Reactive Zone for Perchlorate Treatment, Jet Propulsion Laboratory Test Area.* March.

California Regional Water Quality Control Board (RWQCB). 1994. *Water Quality Control Plan: Los Angeles Region, Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties.* Regional Water Quality Control Board Los Angeles Region. June.

California Regional Water Quality Control Board (RWQCB). 2005. *Water General Waste Discharge Requirements for Groundwater Remediation at Petroleum Hydrocarbon Fuel and/or Volatile Organic Compound Impacted Sites.* File No. 01-116. Regional Water Quality Control Board Los Angeles Region. April.

Ebasco. 1988. *Preliminary Assessment/ Site Inspection Report for Jet Propulsion Laboratory, Pasadena, California.* April.

Ebasco. 1990a. *Expanded Site Inspection Report for NASA-Jet Propulsion Laboratory, Pasadena, California.* May.

Ebasco. 1990b. *Supplemental Information to the Expanded Site Inspection Report for NASA-Jet Propulsion Laboratory, Pasadena, California.* November.

Foster Wheeler Environmental Corporation (FWEC). 1996. *Scoping Assessment of Ecological Risk at the Jet Propulsion Laboratory, Pasadena, California.* September.

Foster Wheeler Environmental Corporation (FWEC). 1999a. *Final Remedial Investigation Report for Operable Units 1 and 3: On-Site and Off-Site Groundwater.* National Aeronautics and Space Administration, Jet Propulsion Laboratory, Pasadena, CA. August.

Foster Wheeler Environmental Corporation (FWEC). 1999b. *Final Remedial Investigation Report for Operable Unit 2: Potential On-Site Contaminant Source Areas.* National Aeronautics and Space Administration, Jet Propulsion Laboratory, Pasadena, CA. November.

Foster Wheeler Environmental Corporation (FWEC). 2000. *Draft Feasibility Study Report for Operable Units 1 and 3: On-Site and Off-Site Groundwater.* National Aeronautics and Space Administration, Jet Propulsion Laboratory, Pasadena, CA. January.

National Aeronautics and Space Administration (NASA). 1994. *Final Superfund Community Relations Plan.* NASA Jet Propulsion Laboratory. NAS7.000794, NASA-JPL, SSIC No. 9661. January.

Interim ROD, OU 1 Source Area Groundwater   53   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

National Aeronautics and Space Administration (NASA). 2002. *Final Record of Decision and Remedial Action Plan for Operable Unit 2, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California.* September.

National Aeronautics and Space Administration (NASA). 2003a. *Revised Final Operable Unit 1 Expanded Treatability Study Work Plan.* NASA Jet Propulsion Laboratory. NAS7.010106, NASA-JPL, SSIC No. 9661. October.

National Aeronautics and Space Administration (NASA). 2003b. *Final Community Relations Plan: Amendment 1.* NASA Jet Propulsion Laboratory. NAS7.010106, NASA-JPL, SSIC No. 9661. January.

National Aeronautics and Space Administration (NASA). 2005a. *Proposed Plan For Source Area Groundwater Cleanup at the NASA Jet Propulsion Laboratory, Pasadena, California.* November.

National Aeronautics and Space Administration (NASA). 2005b. *Operable Unit 1 Expanded Treatability Study Installation Report, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California.* June.

National Aeronautics and Space Administration (NASA). 2005c. *Technical Memorandum: Operable Unit 1 Quarterly Progress Report, Expanded Treatability Study System Operations, January to March 2005.* April 11.

National Aeronautics and Space Administration (NASA). 2005d. *Technical Memorandum: Operable Unit 1 Demonstration Study Progress Report, April to August 2005, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California.* October.

National Aeronautics and Space Administration (NASA). 2006a. *Technical Memorandum: Operable Unit 1 Demonstration Study Progress Report, September 2005 to February 2006, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California.* April.

National Aeronautics and Space Administration (NASA). 2006b. *Proposed Plan to Fund Construction and Operation of Treatment Systems for Groundwater from Drinking Water Wells Located near the National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California.* April.

National Aeronautics and Space Administration (NASA). 2006c. *National Environmental Policy Act of 1969 (NEPA) Values Assessment for the National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California.* November.

National Aeronautics and Space Administration (NASA). 2006d. *Technical Memorandum: 2005 Groundwater Monitoring Summary (Including Fourth Quarter 2005 Sampling Event), National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California*. January.

National Aeronautics and Space Administration (NASA). 2006e. *Perchlorate Treatment Technologies Literature Review, Operable Unit 1 Expanded Treatability Study, National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, California*. June.

United States Environmental Protection Agency (U.S. EPA). 1989a. *Risk Assessment Guidance for Superfund: Volume I Human Health Evaluation Manual (Part A)*. Interim Final. Office of Emergency and Remedial Response, EPA/5401/1-89/002. December.

United States Environmental Protection Agency (U.S. EPA). 1989b. "Applicability of Land Disposal Restriction to RCRA and CERCLA Ground Water Treatment Reinjection, Superfund Management Review: Recommendation No. 26." Memorandum from Don R. Clay, Assistant Administrator, Office of Solid Waste and Emergency Response. OSWER Directive No. 9234.1-06. December.

United States Environmental Protection Agency (U.S. EPA). 1992a. *The Superfund Accelerated Cleanup Model (SACM) under CERCLA and the NCP*. Office of Solid Waste and Emergency Response Directive 9283.1-06. May.

United States Environmental Protection Agency (U.S. EPA). 1992b. "Permits and Permit 'Equivalency' Processes for CERCLA On-Site Response Actions." Memorandum from Henry L. Longest II, Director, Office of Emergency and Remedial Response. OSWER Directive No. 9355.7-03. February.

United States Environmental Protection Agency (U.S. EPA). 1996. *Presumptive Response Strategy and Ex Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites*. Office of Solid Waste and Emergency Response. EPA 540/R-96/023. October.

United States Environmental Protection Agency (U.S. EPA). 1999. *A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents*. Office of Solid Waste and Emergency Response. EPA 540/R-98/031. July.

United States Environmental Protection Agency (U.S. EPA). 2000. *Applicability of RCRA Section 3020 to In-Situ Treatment of Ground Water*. Memorandum from Elizabeth A. Cotsworth, Director Office of Solid Waste, Office of Solid Waste and Emergency Response. Washington, DC. December.

United States Environmental Protection Agency (U.S. EPA). 2002. *Handbook of Groundwater Protection and Cleanup Policies for RCRA Corrective Action for Facilities Subject to*

Corrective Action Under Subtitle C of the Resource Conservation and Recovery Act.
Office of Solid Waste and Emergency Response. EPA/530/R-01/015.

Interim ROD, OU 1 Source Area Groundwater   56   Rev. 1
NASA Jet Propulsion Laboratory   December 2006
Part II: Decision Summary

Part III: THE RESPONSIVENESS SUMMARY

This Responsiveness Summary is a part of the Record of Decision (ROD) for Operable Unit 1 (OU-1), source area groundwater remediation for the National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory (JPL). The purpose of the Responsiveness Summary is to provide a summary of and responses to the public's comments, concerns and questions received about NASA's *Proposed Plan for Source Area Groundwater Cleanup*, dated November 1, 2005.

NASA held a meeting on November 16, 2005, to formally present the Proposed Plan for source area groundwater cleanup to the community, and to answer questions and receive comments regarding the OU-1 system expansion. A Public Comment Period from November 1, 2005 to December 15, 2005 gave the public the opportunity to ask specific questions and make formal comments for the record. The transcript from this meeting, which may be found at the information repositories or on the Web site http://jplwater.nasa.gov, is a part of the Administrative Record for the site. The Responsiveness Summary is organized as follows:

1.0   Overview
2.0   Background on Community Involvement
3.0   Comprehensive Summary of Major Public Questions, Comments and Concerns, and NASA Responses
4.0   Comprehensive Summary of Major Regulatory Questions, Comments and Concerns, and NASA Responses
5.0   Acronyms and Abbreviations
6.0   References

1.0 OVERVIEW

As part of the November 16, 2005, Public Meeting held during the Public Comment Period, NASA presented the preferred alternative for OU-1 source area groundwater (NASA, 2005). NASA proposed expansion of the existing demonstration treatment system utilizing the extraction, treatment and reinjection system to remove volatile organic compounds (VOCs) and perchlorate to prevent further migration in the groundwater to off-site areas.

No changes to the preferred alternative and no new alternatives that had not previously been considered by NASA were suggested by the public during the public comment period. No changes in the preferred alternative are now proposed in the Record of Decision.

The selected remedy for cleanup of perchlorate and VOCs in the groundwater beneath JPL is the continued operation and expansion of the existing demonstration treatment system. The existing system consists of a two-step treatment process. The first step is VOC removal; VOCs are removed from the groundwater by filtration through liquid-phase granular activated carbon (LGAC). The second step is perchlorate removal, achieved by using a fluidized bed reactor (FBR) unit. The FBR uses a biological process to break down and remove perchlorate from groundwater. New extraction and injection wells will be installed to more than double the amount of water being treated from a rate of approximately 150 gallons per minute (gpm) to a rate of approximately 350 gpm (NASA, 2005). A detailed description of the selected remedy is provided in Section 12.0 of the ROD.

Interim ROD, OU 1 Source Area Groundwater   58   Rev. 0
NASA Jet Propulsion Laboratory   November 2006
Part III: Responsiveness Summary

2.0 BACKGROUND ON COMMUNITY INVOLVEMENT

Initial interviews with community members and leaders in 1991 and again in 1993 indicated a relatively low level of awareness in the three surrounding communities of La Cañada Flintridge, Altadena, and Pasadena regarding the placement of JPL on the National Priorities List (NASA, 2003). During these interviews residents suggested using community newsletters to convey important information in addition to the media sources NASA was already using (NASA, 2003). NASA attempted to address these concerns through community newsletters and fact sheets distributed to members of the surrounding communities.

In May and June 2001, three public meetings were held to inform the public of the remediation alternatives considered as part of the Proposed Plan to clean up on-facility soils at JPL and a Public Comment Period gave the public a chance to ask questions and state their concerns about on-facility soils treatment. Comments submitted during the public comment period were collected and reviewed.

In January 2004, NASA held two public meetings and a meeting for JPL employees to solicit community input into the cleanup process and to update the community on NASA's groundwater cleanup efforts and plan. In April 2004, a Community Meeting on Health was held. A panel of medical and public health experts gathered, along with NASA Project and Community Outreach Managers to address questions from the public about the health effects of perchlorate and target volatile organic compounds at the JPL site (NASA, 2004).

Additional interviews of local residents, community leaders, and two JPL employees in January 2005 showed a much greater level of awareness about the Groundwater Cleanup Program, with residents commenting on their appreciation of NASA's efforts to communicate with the public (NASA, 2006).

In March 2005, NASA hosted a Community Information Session. Local residents met with members of NASA's Groundwater Cleanup Project team, local water purveyors, and health and technical experts to learn about the progress NASA has made in cleaning up groundwater beneath the Jet Propulsion Laboratory and areas adjacent to it.

NASA held a Public Meeting on the Proposed Plan for OU-1 on November 16, 2005. Public notifications of the Proposed Plan and public meeting were mailed as a newsletter to the residents of the surrounding communities, and were e-mailed to approximately 5,000 JPL employees. Public notification of the meeting on November 16 was provided in local newspaper notices. The meeting was held to present the Proposed Plan to the public and obtain official public comments. The public comment period was open from November 1 through December 15, 2005. During this time, members of the public had the opportunity to comment on and ask questions about the information presented in the public meetings and in the Proposed Plan. NASA responses to all written and oral comments received during the public comment period are provided in the following section. Oral comments were made during the public meeting and can be found in the transcript of the meeting in the Administrative Record on the program Web site (http://jplwater.nasa.gov) or at any of the following Information Repositories:

La Cañada Flintridge Public Library
4545 Oakwood Avenue
La Cañada Flintridge, CA 91011
(818) 790-3330

Pasadena Central Library
285 E. Walnut Street
Pasadena, CA 91101
(626) 744-4052

Altadena Public Library
600 E. Mariposa Avenue
Altadena, CA 91001
(626) 798-0833

JPL Library
(JPL Employees Only)
4800 Oak Grove Drive
Bldg. 111-112
Pasadena, CA 91109
(818) 354-4200

3.0 COMPREHENSIVE SUMMARY OF PUBLIC QUESTIONS AND COMMENTS AND NASA RESPONSES

The Public Comment Period for the Proposed Plan for Source Area Groundwater Cleanup at the NASA Jet Propulsion Laboratory, Pasadena, California extended from November 1, 2005 through December 15, 2005. A public meeting to provide background on and summarize the Proposed Plan and obtain public comments on the record was held November 16, 2005.

Only one letter of comment was received and one comment card was submitted during the public meeting held concerning the Proposed Plan on November 16, 2005. A number of speakers made comments or asked questions during the public meeting of November 16, 2005. In addition, in response to an email to all JPL personnel, dated November 1, 2005, questions were submitted by email pertaining to the Proposed Plan. These comments are identified below.

Each of the comment letters and other documents was reviewed, and individual significant comments within each document were identified. The email inquiries from JPL employees were responded to the sender immediately upon receipt and, as they were received during the official comment period, also are included here.

1. General Comments
Note: In some cases the email questions and answers and the public comments and responses made on November 16, 2005 to the public comments have been slightly modified for this Responsiveness Summary, to ensure that the information is updated and is easy to read in context. The original comments and responses during the November 16, 2005 public meeting are available on the transcript provided at: http://jplwater.nasa.gov

1a. Melody Comfort, Local Resident:
I consider the new plan to be responsive to all the ecological needs for the community, specifically at the JPL site, and generally for the surrounding residents, schools and businesses. From the information that I gained at this 11-16-2005 Community meeting, I consider the plan to be a sound one, utilizing access to some of the existing features of the current water treatment facility. I appreciate public updates, and the opportunity to gain clarification on my issues of concern. Thank you.

NASA Response:
NASA acknowledges and appreciates your feedback.

1b. Dorothy Thorman, Altadena Resident:
I will just make the statement that I am very glad that this process is taking place, because you know, it is wonderful. And it would be nice if all these sites that I hear there are so many toxic [Superfund] sites. And this administration has cut back on the funding for these cleanups. So I think we are very fortunate to have this taking place.

NASA Response:
NASA acknowledges and appreciates your feedback.

Interim ROD, OU 1 Source Area Groundwater   61   Rev. 0
NASA Jet Propulsion Laboratory   November 2006
Part III: Responsiveness Summary

2. Health Implications

2a. Barbara Benton, Altadena Resident:
My name is Barbara Benton. Anyway, I spoke before this whole thing got started because I had stopped at the corner of my street about two or three years ago when they were testing one of the wells. And I said "What are you doing?" So my concern as a retired nurse and as a 35-year resident of the area, are the health implications. We have had many deaths in my community, mostly of cancer, various kinds. We had a doctor that I used to work with at USC last year. He says it doesn't show up in the records—demographic records for cancer. We have had several deaths since I was here. And I am truly concerned about my own health. I wasn't here in March. And as I think back, I was having some GI problems, and I went to the doctor, and there's something on my pancreas, which isn't cancerous, but why is it there? How did it get there? You know, they biopsied it and said it was nonmalignant. And it may or may not have had anything to do with it. But I lived here for 35 years. There has to be chemical implications; otherwise, why do you want to clean it up? You see. And I want somebody to address that. And I think all your charts and pretty pictures are nice, but the issue is, how is it impacting the health of not just the residents, but the JPL employees who have been there for a career. I want to know. And I want somebody to tell me the truth.

NASA Response:
NASA recognizes the deep concern you and other members in your community have for their own health, and the health of animals in the area. This is the reason NASA seeks to fund both on and off-site treatment of the chemicals in the groundwater.

The Agency for Toxic Substances and Disease Registry (ATSDR) conducted site visits in 1997 to assess the potential for public health hazards at JPL. Following a careful evaluation of available data, ATSDR determined that the volatile organic compounds (VOCs) in groundwater do not present a past, present, or future public health to JPL employees or nearby residents. Based on their findings, they also deemed it unlikely that perchlorate in groundwater posed a past public health hazard (ATSDR, 1998).

In January 2005 the Committee to Assess the Health Implications of Perchlorate Ingestion, National Research Council of the National Academies of Science released a study of the health implications of perchlorate ingestion. The study found no harmful effects of perchlorate at mild levels, such as those seen in the local drinking water supply (NAS, 2005). Reports of both studies can be found on the Web site at http://jplwater.nasa.gov.

NASA has made efforts to disseminate information and address public concerns about potential health effects. A Community Meeting on Health was held in April 2004 and independent medical specialists were on hand to answer questions and report findings (NASA, 2004). More information about what the medical specialists shared with the community can be found on the main page of the Web site (http://jplwater.nasa.gov).

Interim ROD, OU 1 Source Area Groundwater   62   Rev. 0
NASA Jet Propulsion Laboratory   November 2006
Part III: Responsiveness Summary

2b. Marietta Kruells, Altadena Resident:
My name is Marietta Kruells. I'm a 20-plus year resident in Altadena. And I would like to know if it's possible to have medical information from veterinarians included in this because I think that is something that has been ignored, and I have mentioned it before, that there's a lot of horses in the area, and they are a pretty easy target—they only drink water here. They usually don't travel. They don't drink bottled water. And so I think that would be a good group to look for medical problems. That was it. Thank you.

NASA Response:
Thank you for your comment. NASA acknowledges and will consider your feedback.

3. OU-1 Onsite Treatment System

3a. Dorothy Thorman, Altadena Resident:
Does this plan clean the volatile compounds [VOCs] at the same time as the perchlorate?

NASA Response:
Yes, the water is pumped up into the treatment plan and the carbon filters take out the VOCs and then the water goes into the fluidized be reactor (FBR) where the bugs destroy the perchlorate.

3b. Melody Comfort, Altadena Resident
When the bacteria ingest the perchlorate, what really happens to the bacteria?

NASA Response:
The bacteria do not actually ingest the perchlorate. The bacteria ingest citric acid and nutrients, and while doing so release an enzyme that reduces the perchlorate to chloride and oxygen. The bacteria live and reproduce, continuing to breakdown the perchlorate. Eventually the bacteria become old and die, and result in an innocuous biomass that is safely disposed (ITRC, 2005).

3c. Melody Comfort, Altadena Resident:
If there was an earthquake and the tank fell over, are the bacteria from the FBR system harmless? They don't have any perchlorate and there are no dangerous compounds within the bacteria?

NASA Response:
The bacteria are harmless. The bacteria do not concentrate any of the perchlorate, but simply cause the perchlorate to break down during stable continuous operating conditions. If the FBR system was upset during an earthquake, groundwater extraction and treatment would automatically shut off.

3d. Unidentified Speaker at November 2005 Public Meeting:
It is a dollar constraint of a million dollars that[NASA Project Manager Steve Slaten]) is talking about just doubling the flow? Why not go ten times?

NASA Response:
Thorough investigation by NASA and its contractors about the location of the chemicals in the source areas, as well as the permeability of the aquifer below JPL, suggest that expansion of the system to 350 gpm will best balance a number of aspects including removal of the chemicals, capacity to extract and reinject the water from and back to the aquifer, and the speed of cleanup.

3e. Dick Fiedler, Lincoln Avenue Water Company Board of Directors:
Do you have to have permits in order to operate the treatment system?

NASA Response:
Yes. NASA has all the permits it needs to comply with all appropriate regulations.

3f. Unidentified Speaker at November 2005 Public Meeting:
Are you going to continue increasing the number of injection and extraction wells of this treatment system after it is up and running?

NASA Response:
A lot has been learned about the system since it was first installed as a demonstration system in 2005. Based on the information, NASA believes that it will be sufficient and give us control of the source area, but NASA will continually evaluate and verify the effectiveness of the treatment of the source area groundwater with this system.

4. Location and Monitoring and Cleanup of Chemicals in the Groundwater

4a. Unidentified Speaker at November 2005 Public Meeting:
Do you know the boundary of the high concentrations in the soil in your water table now?

NASA Response:
Yes. NASA has studied the groundwater in the Raymond Basin, including the direction and the rate of flow and the location of chemicals. There are 25 monitoring wells in the immediate vicinity of JPL, and measurements of chemicals are taken at a total of 82 locations. The information allows NASA to reasonably conclude where the higher concentrations of chemicals in the groundwater are located. This area is referred to as the source area groundwater, and is being addressed in this interim action.

4b. Dorothy Thorman, Altadena Resident:
Are there any other chemicals contaminating the aquifer and are you cleaning up those chemicals?

NASA Response:
All over the country man-made chemicals have gotten into the groundwater, including in the Raymond Basin. As for chemicals disposed of decades ago at JPL, NASA has done various studies and continues to investigate and monitor chemical locations and is cleaning up those target chemicals that originated from the JPL site. While in the cleanup process other chemicals that did not come from JPL are being treated, NASA is only responsible for the cleanup of

chemicals that came from JPL. NASA has identified all of the chemicals for which they are responsible, and are cleaning those up.

4c. Melody Comfort, Altadena Resident:
I would like an update about the new monitoring well located at John Muir High School.

NASA Response:
Initial rounds of sampling from this well show no detectable levels of perchlorate using the approved method for perchlorate analysis, EPA Method 314.0.

4d. Unidentified Speaker at November 2005 Public Meeting:
Does NASA have an idea of the size of the target area it is trying to clean?

NASA Response:
Yes. Our investigation leads us to believe the area of groundwater containing the chemicals is an area of approximately 8-10 acres, by 100-150 feet thick.

4e. Unidentified speaker at November 2005 Public Meeting:
As far as water purveyors go, are the chemicals only in the City of Pasadena and Lincoln Avenue Water Company wells or have they moved into other water purveyors?

NASA Response:
Some wells belonging both to Lincoln Avenue Water Company and the City of Pasadena have been affected at levels that are enough above the standards that they had to be shut down. These are the only purveyors that have been affected. NASA continues to regularly monitor and closely watch the water of the next closest water companies—Las Flores Water Company and Rubio Cañon Land and Water Association.

4f. Unidentified Speaker at November 2005 Public Meeting:
What standard are you using in order to decide what water needs to be cleaned up?

NASA Response:
Federal and state maximum contaminant levels (MCLs) are being used to determine cleanup areas for volatile organic compounds. There currently is no standard for perchlorate, but the State of California has set a public health goal (PHG) of 6 (six) parts per billion (PPB) and NASA is using that as its guideline until a final standard is set.

4g. Melody Comfort, Altadena Resident:
Do you have proof that the plume has moved over the last year?

NASA Response:
NASA has seen no evidence of the plume moving further away from JPL over the past year.

5. JPL Employee E-mails

5a. Larry Mallet, JPL Employee
The information is rather sparse. There is no clear indication of where wells and ports are, how long they've been operating and the extent to which materials concentrations have been reduced.

It appears that most of the concentrations are in a small 8 acre area. What if the dispersion of toxic materials is much wider and outside of this area? How have you come to the conclusion that primary risk is in an 8 acre area? What if the dispersion of toxic waste is much higher? What if detection is merely reflecting the removal of waste from small local sites around wells, rather than from a widely dispersed area? What arrangements exist for independent review outside of NASA and JPL?

The information reflected is spartan.

What outside/independent organizations have been involved in reviewing NASA/JPL plans?

NASA Response:
These written pieces are one of the ways NASA keeps the community informed. NASA also uses fact sheets that are offered at the JPL Open House and other events in the area and the Web site is updated regularly and includes copies of technical documents and recent reports. In addition, NASA offers public meetings and community involvement sessions, and many people contact us directly for additional information, as you did.

One of your questions regarded dispersion of the chemicals. The current newsletter focuses on the source area, because that is the site where NASA is currently proposing to expand a treatment system. An earlier newsletter, the August Bilingual Newsletter (see http://cercla.jpl.nasa.gov/NMOWeb/adminrecord/docs/NAS710324.pdf), discussed the opening of a NASA-funded plant for Lincoln Avenue Water Company in Altadena. Funding that treatment plant is one of NASA's actions to address chemicals that have dispersed from the source and moved offsite.

To facilitate cleanup of the area, NASA divided the site into what are called Operable Units. Each Operable Unit covers a separate medium (i.e., soils or water) and geographic area. OU-1 pertains to groundwater directly underneath the site occupied by the Jet Propulsion Laboratory. The current newsletter describes how NASA is proposing to expand the successful onsite treatment plant. OU-2 refers to the soils directly underneath JPL, for which remediation via soil vapor extraction for the last few years has been so successful that it is almost complete. OU-3 includes all groundwater outside the JPL fenceline in the Monk Hill subarea, east and southeast of JPL.

The focus of the November 2005 newsletter, and of NASA's public meeting on November 16, 2005 was cleanup of the "source area," an eight-acre portion of OU-1, directly beneath JPL. Cleanup at the source is important to reduce the chemicals that will migrate off-facility and thus will help reduce the length of time required to fully clean up the groundwater plume. NASA

understands, however, that chemicals have migrated beyond the JPL fenceline, thus NASA's cleanup extends to the NASA-funded treatment plant at the Lincoln Avenue Water Company and to our cooperation on cleanup with Pasadena Water and Power.

NASA installed monitoring wells in a broad area to the east and southeast of JPL, to ensure the most efficient cleanup of the area from which chemicals from the JPL site are involved. The first monitoring wells were installed in 1989 and quarterly groundwater monitoring began in 1996. The furthest monitoring well from the JPL site, MW 25, is approximately three miles from the monitoring well considered to be closest to the source of chemicals, MW 7. A map of the well locations is provided in the quarterly groundwater monitoring technical memoranda (http://cercla.jpl.nasa.gov/NMOWeb/AdminRecord/ADMIN_KeyDocuments.asp). The southernmost well (MW 25) is at the City Yard near the 210 freeway at W. Hammond Street in Pasadena.

NASA posts quarterly results of our groundwater sampling results on the webpage, following validation of the data received by each sampling effort. These results are found on the "Key Documents" portion of the Administrative Record on the Web site, at: http://cercla.jpl.nasa.gov/NMOWeb/AdminRecord/ADMIN_KeyDocuments.asp. Many of these 25 wells are "multiport" wells, that is, they have the ability to sample distinct zones within a particular well. There is a total of 82 zones sampled in the 25 wells. (Note: Well MW-2 no longer is in operation).

Even after all the separate actions discussed above are taken, NASA will study what further actions must be taken to constitute a "final remedy" to ensure that all chemicals on- and off-site are cleaned up and treated to the appropriate levels established by federal and state health standards.

Lastly, but importantly, while NASA is the lead federal agency responsible for implementation of these cleanup actions, all our studies and actions are thoroughly reviewed by a number of state and federal regulators, including the U.S. Environmental Protection Agency, the California Regional Water Quality Control Board, the California Department of Toxic Substances Control and the California Department of Health Services.

5b. Robert Smythe, JPL Employee
I am a member of section 383, and involved with optical interferometry. We take precise measurements that can be disrupted by vibration caused by pumps, fans and other sources. If the proposed pumping/processing facility is close to one of our optical laboratories, our ability to acquire the needed data from our experiments could be compromised. Can you tell me where these stations will be located, and will any attempt be made to isolate their vibration sources, both from shaking the ground or from acoustical noises close by?

NASA Response:
NASA understands the concerns of programs such as yours at JPL, and will undertake efforts to preclude impacting your work. The proposed construction will include equipment to drill water wells and dig trenches to bury pipes. This activity will be similar to other common construction

that takes place routinely on JPL.   The location of this activity should be north and south of Bldg 79. These operations will be coordinated with JPL Health and Safety and Facilities to minimize impacts such as noise and vibration, and employees will be notified via Inside JPL and Daily Planet. Four wells and the treatment facility have been operating 24/7 in this area since early this year.

5c. Edouard Schmidtlin, JPL Employee
It is too bad that engineers were careless (or that there were no laws or collect system) tens of years ago, but it is good that we are now doing something about it, in terms of monitoring and cleanup I wonder how deep and wide the plume of pollution is today.
Are the JPL water fountains safe (I am specifically in Bldg. 301) or could the water be polluted from the past?

NASA Response:
Drinking water at JPL meets all safe drinking water standards. The groundwater directly beneath JPL is not used as a drinking water source. The source of drinking water for JPL is Pasadena Water & Power (PWP), owned by the City of Pasadena. The City of Pasadena is required to undertake rigorous and frequent monitoring of its water quality and that information must be reported to the State Department of Health Services which oversees drinking water quality for the State.

The City of Pasadena monitors all of its wells, and in all instances, including historically, has shut down any well when it sees the level of chemical approaching a State health and drinking water standard or guideline. Consequently, each well is shut down prior to reaching a level that would exceed safe drinking water requirements.

NASA has a groundwater program that is cleaning up the residual of chemicals released many decades ago from practices that were common at the time. Current use of chemicals is strictly controlled, and all stormwater runoff at JPL is monitored and the data collected show that no releases off-site occur.

The source area of chemicals targeted for cleanup by our onsite treatment plant is an area about 100 feet thick and about eight acres in size.   Groundwater adjacent to JPL has also been impacted at much lower concentrations over hundreds of acres.   This off-facility groundwater is being addressed by cooperating with the neighboring water companies.

5d. Don Langford, JPL Employee
This [sounds acceptable] even though it is disruptive if you work above the JPL firestation.   But I did not see any indication that the chemical count was going down even though 75 million gallons of water have been cleaned up and put back into the ground.   Is there evidence that the underground is getting cleaned up or is it possible that all of La Cañada above JPL is draining into JPL space?

NASA Response:

NASA realizes that construction of the existing plant created some noise, traffic and parking disruptions and appreciates the tolerance all of you located near the construction have shown toward this effort. The additional construction, will consist only of the drilling of two or three wells and connecting pipes to those wells. There will be some loud noises and vibrations associated with drilling of the wells, but the duration of construction is likely to last no more than two months for each well. NASA will be installing one injection well and one extraction well. We will do our best to minimize any disturbance to those employees located in the area.

The on-site treatment plant has been operating since February 2005 and the data indicate that the plant is reducing the chemicals in the groundwater. The plant (that includes its initial start-up period) has removed about 500 pounds of perchlorate and 15 pounds of volatile organic compounds. Further, the most recent influent levels now show 500 ppb of perchlorate, down from 2000 ppb at commencement of the on-site cleanup.

More information may be found at our Web site: http://jplwater.nasa.gov/.

Groundwater from La Cañada Flintridge flows southeasterly from La Cañada Flintridge towards the Arroyo Seco, but it does not flow through this upper part of the JPL site. Monitoring wells south and southeast of JPL may more likely reflect some contribution of chemicals from La Cañada Flintridge.

6. Raymond Basin Management Board (RBMB) Letter

Written questions and comments received by the Raymond Basin Management Board during the Public Comment Period for the Proposed Plan for Source Area Groundwater Cleanup are summarized and addressed below.

6a. General Comment:
The document obtained by the Raymond Basin is a summary of the Proposed Plan; therefore, supporting data and information were not included. The document indicates that "Supporting technical documents are available by visiting any of the public information repositories listed on the last page of this summary or at the NASA JPL Groundwater Cleanup Web site at http://JPLwater.nasa.gov:," however, appropriate technical documents for the Proposed Plan cannot be found on that Web site. The Proposed Plan is Phase II of the expanded treatability study as described in the ETS Work Plan, which adds one additional extraction well and two additional injection wells to the existing demonstration treatment system. Specific comments are based solely on data obtained as described above.

NASA Response:
Applicable backup documentation includes the following:

1. The Expanded Treatability Study Work Plan:
   http://jplwater.nasa.gov/NMOWeb/AdminRecord/docs/NAS710247.htm
2. Installation Report: http://jplwater.nasa.gov/NMOWeb/AdminRecord/docs/NAS710364.htm

3. Groundwater Monitoring Reports:
   http://jplwater.nasa.gov/NMOWeb/AdminRecord/ADMIN_KeyDocuments.asp
4. Progress Report (April – August 2005):
   http://jplwater.nasa.gov/NMOWeb/AdminRecord/docs/NAS710375.pdf

6b. Specific Comment, Page 2:
The Proposed Plan states, "Figure 2 shows the layout of the existing demonstration study system and the proposed expansion. One or two new extraction wells and one or more injection wells will be installed as part of the proposed expansion. The actual number and location of wells will be determined as part of the design phase."

It is unclear if the design refinements will resolve the apparent discrepancy between the proposed expansion, as described in Figure 2 of the Proposed Plan, and Phase II, as described in Figure 1-2 of the ETS Work Plan.

NASA Response:
The design refinements will be documented in an OU-1 Treatment System Expansion Work Plan and will resolve the difference between what was proposed in the Expanded Treatability Study Work Plan (Figure 1-2) and the Proposed Plan (Figure 2).

6c. Specific Comment, Page 2:
The Proposed Plan indicates, "This Proposed Plan summarizes information collected over a number of years. All project-related documentation can be found in the Administrative Record. Copies of the Administrative Record are also available at the information repositories on page 10 and on the project Web site at http://jplwater.nasa.gov."

The Web site does not appear to contain "all project-related documentation," particularly documentation for data interpretation and reporting, as described in Section 5-5 of the ETS Work Plan.

NASA Response:
Please see response to Comment No. 6a above regarding the list of reports that contain recent data and interpretations. More reports will be added to the Web site as they are produced.

6d. Specific Comment, Page 2:
Figure 2 shows that groundwater in the vicinity of the demonstration system generally flows in a north-south direction.

This north-south groundwater flow seems inconsistent with actual water level measurements. According to data in Table F-1 of the Quarterly Progress Report groundwater in that area flowed northeasterly in October 2004 and northwesterly in January, March, and April 2005. This northwesterly flow, which is opposite to the normal southeasterly flow, appears to be the most logical explanation for the persistence of groundwater contamination beneath the NASA JPL, as described in the OU3 RI Work Plan. The north-south groundwater flow direction was used in the groundwater flow model which, in turn, was used to design the proposed expanded

treatability study system, including selection of well locations and pumping rates, as described in the ETS Work Plan. As a result, the design appears to be based upon incorrect assumptions.

NASA Response:
Historical groundwater-level elevation data indicate a steep southwest gradient from the mouth of the Arroyo Seco to the OU-1 system area coupled with a southeast gradient from the northeast of JPL. Flow converges to the south of the treatment system and migrates toward the southeast. Data collected from the majority of historical groundwater monitoring events has shown a southerly flow in the vicinity of the system. Groundwater flow in the vicinity of the OU-1 system is relatively stagnant, and as a result groundwater-level elevations may indicate differing flow directions during select monitoring events. However, overall groundwater flow is historically toward the south in this area, as further evidenced by inclusion of recent groundwater level elevation data from upgradient monitoring well IRZ-IW2, which exhibits groundwater levels higher than those in MW-7. The groundwater elevation contour maps showing conditions after system startup in April and July 2005 (documented in the Progress Report [April – August 2005], see response to comment No. 1) indicate groundwater flow is significantly affected by operation of the system, with a drawdown of roughly 25-30 ft observed in the extraction wells and radial flow observed toward these wells. Although no groundwater level elevation data were collected from the injection wells, monitoring data indicate that it appears that that extraction wells will effectively contain groundwater within a 150-ft radius of the extraction wells and the groundwater injected upgradient at IW-1 and IW-2.

6e. Specific Comment, Page 5:
One of the objectives of the Proposed Plan is to "remove chemicals in groundwater and prevent the further spread of VOCs and perchlorate from the groundwater source area." Because groundwater beneath the source area appears to flow in a southeasterly direction, extraction at Wells EW-1 and EW-2 most likely will not adequately capture contaminated groundwater in the vicinity of MW-7. Based solely on the accessible background data it appears that injection at Wells IW-1 and IW-2 would actually push groundwater down gradient toward MW-11.

NASA Response:
Groundwater monitoring data has indicated that groundwater flow in the immediate vicinity of the OU-1 system is toward the south or south/southwest. Groundwater-level elevation data collected since system startup have indicated that it appears the extraction wells effectively contain groundwater within a 150-ft radius of the extraction wells and the groundwater injected upgradient at IW-1 and IW-2. Therefore, the monitoring data indicate that chemicals in groundwater in the vicinity of MW-7 will be contained by the ETS extraction wells, and not migrate toward downgradient monitoring wells.

6f. Comment 1 from Raymond Basin Management Board
Since JPL plans to extract water from the Basin, how will JPL replenish the basin to cover water lost in the process?

Interim ROD, OU 1 Source Area Groundwater   71   Rev. 0
NASA Jet Propulsion Laboratory   November 2006
Part III: Responsiveness Summary

NASA Response:
The volume of water discharged to the sanitary sewer in the treatment process will be *deminimus*. In fact, through November 2005 NASA has injected more water than it has extracted. Therefore, NASA does not need to cover water lost in the process.

Since completing construction of the facility, NASA has treated and reinjected approximately 51M gallons of water (measured by flow meters installed on the extraction and injection well pipelines). Of this 51M gallons, approximately 48,000 gallons (0.15 ac-ft) has been discharged to the sanitary sewer or shipped off-site. The remaining treated water has been reinjected back into the aquifer.

As you know, in response to your earlier concerns regarding discharged water, NASA installed a clarification system at an additional cost of several hundred thousand dollars that minimizes the amount of water discharged to the sanitary sewer by concentrating the solids prior to batch discharge to the sanitary sewer. Wastewater from the OU-1 plant is discharged in batches of 12,000 gallons. To date, three discharges have been conducted, as summarized in [the table below]. Another 12,000 gallons of wastewater was hauled offsite for disposal.

Summary of Discharges to the Sanitary Sewer

Batch Number	Date of Discharge	Volume
1	April 5, 2005	12,000
2	September 26, 2005	12,000
3	October 31, 2005	12,000
	Total	**36,000**

Discharge to the sanitary sewer is conducted in accordance with the Los Angeles County Sanitation District (LACSD) industrial waste discharge permit for JPL. The OU-1 plant was inspected in November 2005 by the LACSD and the system was in full compliance.

The concrete pad is fully contained by a twelve inch concrete curb. The area within the curb is 3,590.75 ft^2 and drains to the sump that is part of the clarification system. Therefore, any rainwater that falls within the curbed area of the treatment facility is captured by the system and eventually injected into the aquifer. Each inch of rain that falls on the pad equates to approximately 2,200 gallons of water entering the system. With over 36 inches of rain falling so far in 2005, an estimated 81,000 gallons (0.25 ac-ft) of rainwater has been processed at the treatment plant and reinjected.

In addition, tap water is used for various purposes within the curbed area of the concrete pad. This water drains to the sump. To date, approximately 2,500 gallons of water has been used (based on the water meter installed at the facility). Therefore, over 83,000 gallons (0.255 ac-ft) of rainwater and tap water has been injected into the aquifer by the treatment system. This volume significantly exceeds the volume of water discharged to the sanitary sewer or hauled off-site (i.e., 48,000 gallons).

The proposed system expansion would double the treatment flow rate. Based on system operations to date, NASA does not expect discharged water volumes to exceed 0.5 ac-ft/yr after system expansion. Additionally, NASA will consult with the Board prior to any operational changes that could result in discharged water of over 2 ac-ft per year.

6g. Comment 2 from Raymond Basin Management Board
Please provide formal documentation to the board that your proposed cleanup project in OU-1 is in full compliance with all legal and regulatory requirements of the Regional Water Quality Control Board, the Department of Health Services, and U.S. Environmental Protection Agency, and any other agencies with jurisdiction over your project.

NASA Response:
The NASA-JPL Federal Facilities Agreement (FFA) was finalized in December 1992 and signed by NASA, the U.S. Environmental Protection Agency, the California Regional Water Quality Control Board, and the California Department of Toxic Substances Control. The FFA is the regulating document for the NASA-JPL Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Program and provides the formal documentation requested. NASA has received approval from all FFA parties, including the Regional Water Quality Control Board, for the OU-1 Expanded Treatability Study. The FFA is available online at: http://jplwater.nasa.gov/NMOWeb/AdminRecord/docs/NAS70753.pdf. State agency approval documents are also in the Administrative Record.

6h. Comment 3 from Raymond Basin Management Board
The Board understands you have completed some groundwater modeling for your project specific to OU-1. Please provide the Board with all documents and electronic files relating to the groundwater modeling work you are performing.

NASA Response:
NASA has been closely coordinating groundwater modeling efforts with the Raymond Basin Management Board. NASA provided electronic files associated with modeling efforts to the Raymond Basin Management Board in September 2003, January 2004, and February 2004, and conducted a meeting with representatives from the RBMB on March 31, 2005. Please let me know if these files should be provided to others.

5.0 ACRONYMS AND ABBREVIATIONS

AR   Administrative Record
ATSDR   Agency for Toxic Substances and Disease Registry

EPA   United States Environmental Protection Agency

FBR   fluidized bed reactor
FS   feasibility study

GAC   granular activated carbon
gpm   gallons per minute

ITRC   Interstate Technology and Regulatory Council

JPL   Jet Propulsion Laboratory

LGAC   liquid-phase granular activated carbon

M   million
MW   monitoring well

NASA   National Aeronautics and Space Administration
NPL   National Priorities List

OU   operable unit

PHG   public health goal
PPB   parts per billion

RBMB   Raymond Basin Management Board
RI   Remedial Investigation
ROD   Record of Decision

SVE   soil vapor extraction

VOC   volatile organic compound

6.0 REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR). 1998. *Public Health for Jet Propulsion Laboratory.* U.S. Department of Health and Human Services.

Interstate Technology and Regulatory Council (ITRC). 2005. *Perchlorate: Overview of Issues, Status, and Remedial Options.* September.

National Academies of Science (NAS). 2005. *Health Implications of Perchlorate Ingestion.* National Research Council of the National Academies, Board on Environmental Studies and Toxicology, Division of Earth and Life Studies.

National Aeronautics and Space Administration (NASA). 2003. *Final Community Relations Plan: Amendment 1.* NASA Jet Propulsion Laboratory. NAS7.10383, NASA-JPL SSIC No. 9661. January 23.

National Aeronautics and Space Administration (NASA). 2004. *Summary of NASA-JPL Groundwater Cleanup Community Meeting on Health.* NASA Jet Propulsion Laboratory. NAS7.010386, NASA-JPL SSIC No. 9661. June 3.

National Aeronautics and Space Administration (NASA). 2005. *Proposed Plan for Source Area Groundwater Cleanup at NASA-JPL.* NASA Jet Propulsion Laboratory. NAS7.010383, NASA-JPL SSIC No. 9661. November 1.

National Aeronautics and Space Administration (NASA). 2006. *Final Community Relations Plan: Amendment 2.* NASA Jet Propulsion Laboratory. NAS7.010388, NASA-JPL SSIC No. 9661. March 15.

Appendix A
Administrative Record Index for OU-1

RECORD NUMBER	RECORD DATE	SUBJECT	AUTHOR AFFILIATION
010371	11/01/2005	NOVEMBER 2005 BILINGUAL NEWSLETTER	NASA
010382	11/01/2005	PROPOSED PLAN FACT SHEET FOR SOURCE AREA GROUNDWATER CLEANUP AT NASA JET PROPULSION	NASA
010383	11/01/2005	PROPOSED PLAN FOR SOURCE AREA GROUNDWATER CLEANUP AT THE NASA JET PROPULSION	NASA
010378	10/27/2005	TECHNICAL MEMORANDUM: THIRD QUARTER 2005 GROUNDWATER MONITORING RESULTS, OCT. 14, 2005	BATTELLE
010375	10/07/2005	TECHNICAL MEMORANDUM OPERABLE UNIT 1 DEMONSTRATION STUDY PROGRESS REPORT, APRIL TO	BATTELLE
010367	08/30/2005	TECHNICAL MEMORANDUM: SECOND QUARTER 2005 GROUNDWATER MONITORING RESULTS	BATTELLE
010369	07/11/2005	TECHNICAL MEMORANDUM OPERATIONS SUMMARY: JANUARY 2005 THROUGH JUNE 2005 NATIONAL	BATTELLE
010364	06/01/2005	FINAL OU-1 EXPANDED TREATIBILITY STUDY - JUNE 1, 2005	BATTELLE
010362	04/15/2005	TECHNICAL MEMORANDUM FIRST QUARTER 2005 GROUNDWATER MONITORING RESULTS	BATTELLE
010357	03/02/2005	FINAL GROUNDWATER MONITORING REPORT	GEOFON
010366	03/01/2005	MARCH 2005 NEWSLETTER - UPDATE ON GROUNDWATER CLEANUP PROJECT	NASA
010347	01/04/2005	FINAL QUARTERLY GROUNDWATER MONITORING REPORT, JULY-AUGUST 2004	GEOFON
010328	09/08/2004	FINAL QUARTERLY GROUNDWATER MONITORING REPORT, APRIL-MAY 2004	GEOFON
010324	08/14/2004	BILINGUAL NEWSLETTER: AN UPDATE ON GROUNDWATER CLEANUP ACTIVITIES AT JPL, AUGUST 2004	NASA
010322	07/16/2004	FINAL QUARTERLY GROUNDWATER MONITORING REPORT, FEBRUARY 2004	GEOFON
010332	05/01/2004	MAY 2004 NEWSLETTER: NASA BEGINS CONSTRUCTION AT JPL OF GROUNDWATER TREATMENT UNIT	NASA
010301	04/20/2004	POSTCARD SENT TO RESIDENTS AND AN INFORMATIONAL FLYER ANNOUNCING A COMMUNITY MEETING	NASA
010292	02/05/2004	FINAL QUARTERLY GROUNDWATER MONITORING REPORT (Q4), OCTOBER-NOVEMBER 2003	GEOFON
010326	02/05/2004	FINAL QUARTERLY GROUNDWATER MONITORING REPORT (Q2), APRIL-MAY 2003	GEOFON
010327	02/05/2004	FINAL QUARTERLY GROUNDWATER MONITORING REPORT (Q3), JULY-AUGUST 2003	GEOFON
010283	01/27/2004	BROCHURES, FACT SHEETS, AND TRANSCRIPTS FROM THE PUBLIC MEETINGS HELD IN JANUARY 2004	NASA
010302	01/23/2004	NEWSPAPER ANNOUNCEMENTS ON JANUARY 23 AND 27, 2004 IN THE PASADENA STAR-NEWS	NASA
010247	10/16/2003	REVISED FINAL OPERABLE UNIT 1 EXPANDED TREATABILITY STUDY WORK PLAN	BATTELLE
010325	09/03/2003	FINAL QUARTERLY GROUNDWATER MONITORING REPORT (Q1), JANUARY-FEBRUARY 2003	GEOFON
010277	06/30/2003	FIELD PILOT TESTING OF A DYNAMIC SUSPENDED BED REACTOR FOR REMOVAL OF PERCHLORATE IN	FOSTER WHEELER
010280	05/27/2003	FINAL ANNUAL REPORT ON THE JPL LONG TERM GROUNDWATER MONITORING PROGRAM FROM	SOTA
010279	04/09/2003	FINAL QUARTERLY GROUNDWATER MONITORING REPORT FOR OCTOBER TO NOVEMBER 2002	SOTA
010106	01/23/2003	FINAL COMMUNITY RELATIONS PLAN: AMENDMENT 1	NASA
010282	10/10/2002	WORK PLAN FOR A PILOT STUDY TO CREATE AN IN SITU REACTIVE ZONE AND DEMONSTRATE	ARCADIS
010278	10/08/2002	FINAL QUARTERLY GROUNDWATER MONITORING REPORT FOR JULY 2002	SOTA
010005	08/06/2002	QUARTERLY GROUNDWATER MONITORING REPORT, APRIL-MAY 2002	SOTA
010004	04/05/2002	QUARTERLY GROUNDWATER MONITORING REPORT, JANUARY-FEBRUARY 2002	SOTA
010003	01/18/2002	QUARTERLY GROUNDWATER MONITORING REPORT, OCTOBER 2001	SOTA
010002	10/12/2001	QUARTERLY GROUNDWATER MONITORING REPORT, JULY 2001	SOTA
002445	07/27/2001	GROUNDWATER MONITORING REPORT - APRIL, 2001	SOTA
002442	04/27/2001	QUARTERLY GROUNDWATER MONITORING REPORT - JANUARY 2001 THROUGH FEBRUARY 2001	SOTA
002095	03/01/2001	FINAL FOURTH ANNUAL REPORT ON QUARTERLY GROUNDWATER MONITORING - NOVEMBER 1999	FOSTER WHEELER
002106	02/01/2001	FINAL QUARTERLY GROUNDWATER MONITORING RESULTS - SEPTEMBER 2000 THROUGH OCTOBER 2000	FOSTER WHEELER

Appendix A
Administrative Record Index for OU-1

RECORD NUMBER	RECORD DATE	SUBJECT	AUTHOR AFFILIATION
000215	12/11/2000	TECHNICAL PAPER, "REMOVAL AND DESTRUCTION OF PERCHLORATE AND OTHER ANIONS FROM	CALGON
001130	12/01/2000	QUARTERLY GROUNDWATER MONITORING RESULTS - JULY 2000 THROUGH AUGUST 2000	FOSTER WHEELER
000998	07/01/2000	QUARTERLY GROUNDWATER MONITORING RESULTS - MARCH 2000 THROUGH APRIL 2000	FOSTER WHEELER
000995	03/01/2000	QUARTERLY GROUNDWATER MONITORING RESULTS - NOVEMBER 1999 THROUGH DECEMBER 1999	FOSTER WHEELER
000994	01/01/2000	DRAFT FEASIBILITY STUDY (FS) FOR OU 1 AND OU 3	FOSTER WHEELER
000984	12/01/1999	PERCHLORATE TREATABILITY STUDIES: USE OF REVERSE OSMOSIS AND BIOTREATMENT FOR REMOVAL	FOSTER WHEELER
000993	12/01/1999	QUARTERLY GROUNDWATER MONITORING RESULTS - AUGUST 1999	FOSTER WHEELER
000670	11/12/1999	TRANSMITTAL OF SUPERFUND SOLUTIONS COMMUNITY NEWSLETTER NUMBER 2	JPL
000569	08/05/1999	FINAL PUBLIC HEALTH ASSESSMENT	ATSDR
001001	08/01/1999	FINAL REMEDIAL INVESTIGATION (RI) FOR OU 1 AND OU 3 (VOLUMES I AND II)	FOSTER WHEELER
001000	07/01/1999	QUARTERLY GROUNDWATER MONITORING RESULTS - MAY 1999 THROUGH JUNE 1999	FOSTER WHEELER
000218	06/28/1999	FINAL REPORT FOR REMOVAL OF PERCHLORATE AND OTHER CONTAMINANTS FROM GROUNDWATER AT	CALGON
000999	05/01/1999	QUARTERLY GROUNDWATER MONITORING RESULTS - FEBRUARY 1999 THROUGH MARCH 1999	FOSTER WHEELER
000216	04/06/1999	FINAL PROJECT REPORT "APPLICATION OF ION-EXCHANGE TECHNOLOGY FOR PERCHLORATE REMOVAL	MONTGOMERY WATSON
001008	03/01/1999	QUARTERLY GROUNDWATER MONITORING RESULTS - OCTOBER 1998 THROUGH NOVEMBER 1998	FOSTER WHEELER
000983	12/01/1998	SECOND ANNUAL REPORT ON LONG-TERM QUARTERLY GROUNDWATER MONITORING PROGRAM	FOSTER WHEELER
000541	10/16/1998	NASA JPL TOUR HANDOUT - SUPERFUND BACKGROUND INFORMATION	JPL
001006	10/01/1998	QUARTERLY GROUNDWATER MONITORING RESULTS - JULY 1998 THROUGH AUGUST 1998	FOSTER WHEELER
001012	08/01/1998	QUARTERLY GROUNDWATER MONITORING RESULTS - APRIL 1998 THROUGH MAY 1998	FOSTER WHEELER
001011	04/01/1998	QUARTERLY GROUNDWATER MONITORING RESULTS - JANUARY 1998 THROUGH FEBRUARY 1998	FOSTER WHEELER
000997	03/01/1998	QUARTERLY GROUNDWATER MONITORING RESULTS - SEPTEMBER 1997 THROUGH OCTOBER 1997	FOSTER WHEELER
000976	01/01/1998	QUARTERLY GROUNDWATER MONITORING PROGRAM ANNUAL REPORT AUGUST 1996 TO JULY 1997	FOSTER WHEELER
001005	09/01/1997	QUARTERLY GROUNDWATER MONITORING RESULTS - JUNE 1997 THROUGH JULY 1997	FOSTER WHEELER
001004	04/01/1997	QUARTERLY GROUNDWATER MONITORING RESULTS - FEBRUARY 1997 THROUGH MARCH 1997	FOSTER WHEELER
001003	03/01/1997	QUARTERLY GROUNDWATER MONITORING RESULTS - OCTOBER 1996 THROUGH NOVEMBER 1996	FOSTER WHEELER
001002	12/01/1996	QUARTERLY GROUNDWATER MONITORING RESULTS - AUGUST 1996 THROUGH SEPTEMBER 1996	FOSTER WHEELER
000794	01/01/1994	FINAL SUPERFUND COMMUNITY RELATIONS PLAN (CRP)	JPL
000753	12/30/1992	TRANSMITTAL OF FINAL FEDERAL FACILITY AGREEMENT	USEPA
000849	01/01/1991	REMEDIAL INVESTIGATION/FEASIBILITY (RI/FS) STUDY WORK PLAN	EBASCO
000845	11/01/1990	SUPPLEMENTAL INFORMATION TO THE EXPANDED SITE INSPECTION REPORT (HAZARD RANKING SYSTEM	EBASCO
000843	05/01/1990	EXPANDED SITE INSPECTION REPORT	EBASCO
000240	04/11/1988	PRELIMINARY ASSESSMENT/SITE INSPECTION REPORT	EBASCO

APPENDIX B

PUBLIC NOTICES

AFFIDAVIT OF INSERTION

NASA

This is to certify that the following ad ran in the San Gabriel Valley Newspaper publications on the following dates:

November 1, 9, 15, 2004.

Each ad 31.5 inches with tagline of "Public Comment Period".

Before me, a notary public, personally appeared

Alice Von Lutz
Signature

asst. Credit Manager
Title

State of California
County of Los Angeles
Sworn and subscribed before me
November 18, 2005

EVELYN ADAMS WILSON
Commission # 1406705
Notary Public - California
Los Angeles County
My Comm. Expires Mar 23, 2007
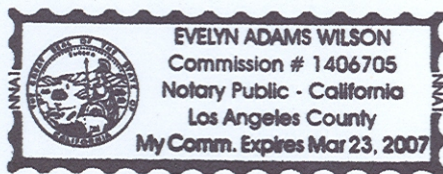
Evelyn Adams Wilson
Notary Public Signature

Public Comment Period
November 1 - December 15, 2005
& Public Meeting

NASA

PROPOSED PLAN FOR
Source Area Groundwater Cleanup
At NASA Jet Propulsion Laboratory

NASA is seeking public comment from November 1 through December 15, 2005 on NASA's Proposed Plan for Source Area Groundwater Cleanup at the Jet Propulsion Laboratory (JPL) site.

NASA invites the public to offer oral or written comments and ask questions about NASA's Proposed Plan at a:

Public Meeting
Wednesday, November 16, 2005
7-9 p.m.
Altadena Community Center
730 E. Altadena Drive, Altadena

During this meeting NASA will explain its proposal to expand the on-site groundwater treatment plant at JPL. Following the presentation, NASA will listen to attendees' formal verbal comments that will be transcribed and become part of the final record when NASA makes its final decision on the proposed action. After NASA formally takes people's comments, attendees will have the opportunity to speak with regulators and NASA's technical experts on a one-on-one basis.

NASA proposes to expand the existing demonstration treatment plant located on JPL at what is termed the "source area." Since it began operating earlier this year, the plant has proven quite successful in removing perchlorate and volatile organic compounds from the source area groundwater where the majority of the chemicals are located. NASA proposes to more than double the amount of water being treated, going from a rate of about 150 gallons per minute (gpm) to a rate of approximately 350 gpm. The system currently uses two wells to extract groundwater, and after the water is treated, two wells re-inject the clean water. NASA's proposed expansion would involve installing one more extraction well and one more injection well to make the system even more effective. The Proposed Plan provides information about the alternatives considered to meet groundwater cleanup objectives and the rationale for the proposed expansion option.

You may review the Proposed Plan and supporting technical documents on the Web at the NASA JPL Groundwater Cleanup Website at http://JPLwater.nasa.gov, by requesting a copy from Merrilee Fellows (below), or by visiting any of the NASA public information repositories located at the:

Pasadena Central Library	Altadena Public Library	La Cañada Flintridge Public Library	JPL Repository
285 E. Walnut St. Pasadena California 91101 **(626) 744-4052**	600 E. Mariposa Ave. Altadena California 91001 **(626) 798-0833**	4545 Oakwood Ave. La Cañada Flintridge California 91011 **(818) 790-3330**	(JPL Employees Only) 4800 Oak Grove Dr. Bldg. 111 **(818) 354-4200**

Comments or questions on NASA's Proposed Plan may be submitted electronically to mfellows@nasa.gov or by mail to the attention of:

Ms. Merrilee Fellows
NASA Water Cleanup Outreach Manager
NASA Management Office, 180-801
Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena, CA 91109

All comments must be submitted electronically by midnight December 15, 2005, or, if comments are posted by mail, the comments must bear a postmark of no later than December 15, 2005.

FINAL

PERCHLORATE (ClO$_4^-$) TREATMENT TECHNOLOGIES LITERATURE REVIEW
OPERABLE UNIT 1 EXPANDED TREATABILITY STUDY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JET PROPULSION LABORATORY
PASADENA, CALIFORNIA

EPA ID# CA9800013030
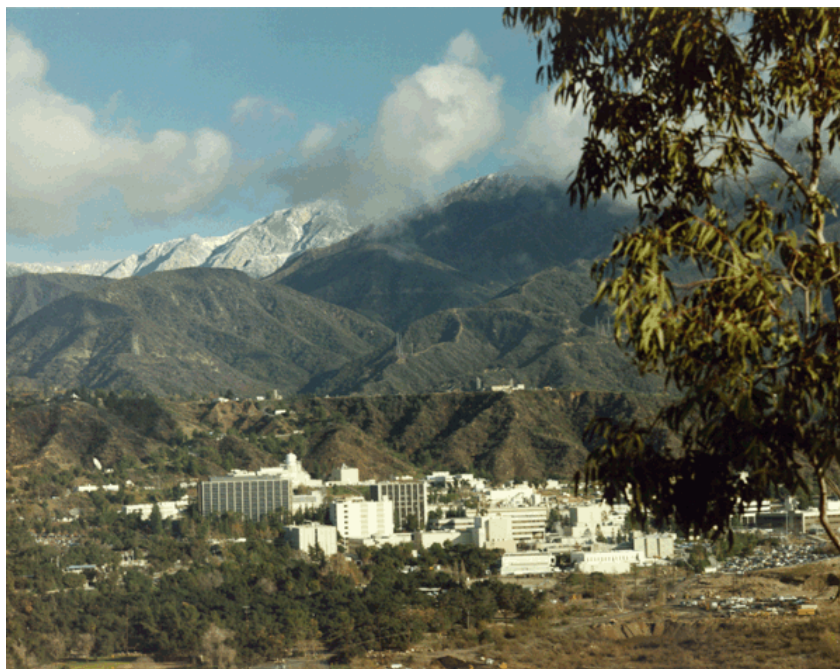
PREPARED FOR:

National Aeronautics and Space Administration
Management Office, Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91101

June 2006

The use of conventional water treatment technologies has proven to be largely ineffective for perchlorate (ClO_4^-) removal because of its low reactivity, low volatility, and high solubility (Urbansky, 1999). Therefore, scientists, regulators, responsible parties, and others in the environmental community have participated in a substantial effort to develop and test more effective methods for the treatment of perchlorate-impacted groundwater. The primary challenge has been to develop technologies that can meet the low ClO_4^- effluent levels required to protect human health, while still cost-effectively treating the large volumes of water handled during remediation and/or drinking water supply projects.

A literature review was completed in order to provide an updated assessment of the development status of various biological, physical, chemical, and thermal treatment technologies used for the removal of ClO_4^- from groundwater. This review consisted primarily of an analysis of published scientific articles, review articles, trade journal articles, recent patents, conference proceedings, and other selected reports available through the United States Environmental Protection Agency (U.S. EPA) Region 9 Superfund Records Center. The primary objective of the review was to highlight the lessons learned from several recent field-scale projects. These results will help to focus the efforts of the planned expanded treatability study at the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) on those ClO_4^- treatment technologies that have the following characteristics: (1) a proven track record of effectiveness in achieving ClO_4^- removal and/or destruction, (2) a history of successful field-scale implementation at JPL or other sites, and (3) favorable project economics.

The Ground Water Remediation Technologies Analysis Center (GWRTAC) recently completed a *Technology Status Report for Perchlorate Treatment Technologies* (2001) and identified 65 laboratory, pilot-scale, and full-scale projects for the remediation of ClO_4^- in soil and groundwater. The report determined that biological treatment methods were the most frequently implemented and/or studied at 69% of case studies, physical methods at 22%, chemical methods at 6%, and 3% unspecified methods. The primary treatment technologies covered in this review are biological, physical, chemical, and thermal methods. The results of several key case studies identified during this literature review are presented. This literature review focuses primarily on projects that have been implemented at the field-scale, but laboratory results are discussed when the studies were completed in conjunction with a field-scale project and/or when no field-scale projects were identified.

It has been widely demonstrated in the literature that ClO_4^- is readily degraded by microbes and that these microbes are present in a variety of environments including pristine and hydrocarbon-contaminated soils, aquatic sediments, and industrial and agricultural waste sludges (Gingras and Batista, 2002). Although the reduction of ClO_4^- is a thermodynamically favorable reaction, the reaction is impeded by a high activation energy, which makes ClO_4^- very chemically stable under normal groundwater and surface water conditions (Urbansky, 1999). However, perchlorate-reducing microbes produce an enzyme that allows them to lower the activation energy for ClO_4^- reduction and to use ClO_4^- as an alternate electron acceptor for metabolism in place of oxygen or nitrate. In order to carry out ClO_4^- reduction, the microbes first need an organic or inorganic electron donor source (e.g., ethanol or H_2 gas) for growth and then utilize the ClO_4^- molecule as a terminal electron acceptor. The enzyme-catalyzed reduction from ClO_4^- to chlorate to chlorite is completed as follows to produce the nontoxic by-products of chloride and oxygen (Logan, 1998).

$$ClO_4^- \quad \rightarrow \quad ClO_3^- \quad \rightarrow \quad ClO_2^- \quad \rightarrow \quad Cl^- + O_2$$
$$\text{Perchlorate} \qquad \text{Chlorate} \qquad \text{Chlorite} \qquad \text{Chloride}$$
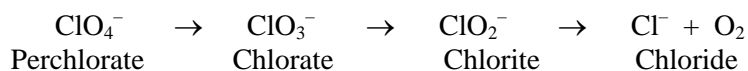
It is clear that both ex situ and in situ biological treatment methods have great potential for the remediation of perchlorate-contaminated groundwater. In fact, more than 69% of the case studies in the GWRTAC study relied upon the biological degradation of ClO_4^- as part of their treatment methodology. Forty-five percent (45%) of the case studies used ex situ biological treatment, 18% used in situ biological treatment, and 6% relied upon an unspecified general biological treatment technique (GWRTAC, 2001). A discussion of key case studies for both ex situ and in situ biological treatment methods are provided below.

Ex Situ Biological Treatment

Ex situ biological treatment involves extracting groundwater from the subsurface and pumping it through a reactor containing a large population of microbes. A steady supply of electron donor is pumped into the reactor to support microbial growth and the subsequent reduction of ClO_4^-. Ex situ biological treatment is one of the most frequently studied and/or implemented ClO_4^- treatment technologies, representing 45% of the case studies in the GWRTAC technology status report (GWRTAC, 2001). The appeal of this treatment method is likely tied both to the ability of microbes to break ClO_4^- down into the nontoxic by-products of chloride and oxygen and to the potential for substantial economic savings over physical and/or chemical treatment methods. One study showed that ex situ biological treatment capital costs were 25% less expensive than a patented ion exchange process, whereas annual operation and maintenance costs were more than 57% less expensive (Harding ESE, 2001). Ex situ biological treatment can be used to treat perchlorate-contaminated groundwater directly or to treat brine wastes generated from separation processes such as reverse osmosis and ion exchange (Gingras and Batista, 2002). The use of biological treatment systems for drinking water purposes is not widespread in the United States and physical and chemical processes are typically viewed as the more conventional approach (Logan, 1998). However, full-scale ex situ biological treatment systems have been carefully evaluated in terms of their process effectiveness, reliability, and control and found to consistently produce treated water to non-detectable levels of perchlorate. The State of California Department of Health Services (DHS) recently accepted the use of biological treatment to remove or reduce perchlorate from source water that might be used as a potable water supply (DHS, 2002).

Several parameters must be considered in the design, construction, and operation of an ex situ biological treatment system including the selection of an appropriate electron donor and the bioreactor configuration.

Based on this review and others, acetate has been used extensively as an electron donor in both laboratory and field studies (Logan, 1998). However, as shown in Table F-1, several other amendments have been tested including ethanol, methanol, H_2 gas, yeast extract, and other food processing wastes. The selection of an amendment is based on several considerations including cost, availability, presence of other chemicals, and favorable kinetics or performance with respect to ClO_4^- reduction. Significant cost savings can be generated through the selection of inexpensive amendments that are waste by-products from the food processing industry or other sources (ESTCP, 2000).

Several types of bioreactor configurations are available, including continuously stirred tank reactors (CSTRs), packed bed reactors (PBRs), and fluidized-bed reactors (FBRs). According to GWRTAC, CSTRs represent 31% of all ex situ biological case studies, PBRs represent 22%, and FBRs are the most frequently utilized bioreactor configuration at 37% of all ex situ biological case studies. The remaining 10% of case studies involved unspecified types of bioreactors. In addition, the commercialization of FBRs appears to be significantly ahead of CSTRs and PBRs, as several of the reported case studies are large-scale pilot and/or full-scale FBR systems rather than laboratory and/or small-scale pilot tests. CSTR applications have generally been limited to the treatment of high-strength industrial wastewaters and not perchlorate-contaminated groundwater where effective treatment of low concentrations (e.g., ~100 µg/L) requires different engineering considerations. In addition, only a few small-scale PBR pilot projects have been implemented and reported in the literature to date with mixed results. In general, PBRs have been reported to have lower ClO_4^- loading rates and more problems with biofouling and process reliability compared with FBRs (Harding Lawson Associates, 1999).

Below, each type of reactor configuration is discussed, along with the key results from several case studies. Also included below is a discussion of more experimental electron donor amendments (e.g., hydrogen) and reactor types (e.g., hollow fiber membrane) that have been reported in the literature.

Continuously Stirred Tank Reactors (CSTRs)

CSTRs involve the development of an active biomass, which is kept in suspension in a liquid-filled tank by mechanical mixing. CSTRs are well suited to the treatment of low flowrates and high concentration industrial wastes. CSTRs are most likely unsuitable for groundwater treatment applications where high flowrates greater than 1,000 gallons per minute (gpm) and low concentrations must be effectively treated (Hatzinger et al., 2002). Residence times for these types of bioreactors are typically on the order of 2 to 4 hours (U.S. EPA, 1993), although one study reported a residence time as high as 24 hours, as opposed to minutes for attached growth bioreactors like PBRs and FBRs (see Table F-1). Because CSTRs are better suited for the treatment of very highly concentrated wastes, they have been implemented as part of a treatment train with ion exchange units. This approach involves using the CSTR to treat the effluent brine created from the regeneration of the ion exchange resin. Applied Research Associates (ARA) has several patents pending and has implemented this treatment train approach at the Thiokol Corporation in Utah as discussed below. This vendor reports that the combination of ion exchange with biological treatment of the brine can be cost-effective at $100 to $200 per acre-foot (ARA, 2003).

CSTRs at Tyndall Air Force Base in Florida, Thiokol Corporation in Utah, and Hodgdon Powder Company in Kansas

A study conducted by the Air Force Research Laboratory (AFRL) reported the development of a 450-gpm CSTR system to remove ammonium perchlorate in process wastewater and secondary waste brine streams

from the production, remanufacturing, testing, and demilitarization of Minuteman II propulsion systems. The pilot-scale system was first tested at Tyndall Air Force Base in Florida and the full-scale system was then installed and operated at Thiokol Corporation in Utah. The primary components of the CSTR system included two bioreactors that could be operated in parallel or series, a clarifier to aid in the retention of biomass, and various feed and waste storage tanks (ESTCP, 2000).

The objectives of the demonstration were to identify a low-cost amendment alternative, to demonstrate that the process was effective and reliable, and to show that a broad range of wastewater compositions could be treated. Several electron donor amendments were tested including brewer's yeast, cheese whey, marshmallow waste, fruit juice wastes, sugars, starches, and acetate. Food waste or carbohydrate by-product was found to be the most effective and economical amendment ($0.16/lb vs. $1.75/lb of ClO_4^- for brewer's yeast). The influent to the CSTR consisted of ClO_4^- brine (~2,800 to 41,000 mg/L) that was diluted to provide a monthly average feed concentration between 300 and 4,600 mg/L. The brine was diluted to provide relatively constant influent conditions because higher ClO_4^- levels >6,000 mg/L were found to inhibit microbial activity.

Perchlorate was consistently removed to levels ranging from 4 to 400 μg/L in the effluent. (The wastewater discharge permit at the facility specified a maximum effluent limit of 10 mg/L for ClO_4^-). Effective treatment was achieved despite the additional challenge of treating wastewater with a high salt content (>2.3% Na^+, K^+, Cl^-) and other impurities (NO_2^-, NO_3^-, and SO_4^{2-}). Chemical oxygen demand (COD) and total suspended solids (TSS) in the effluent were both relatively high at 5,000 mg/L due to both excess nutrients and suspended cell biomass. It was noted that the elevated COD and TSS might necessitate additional treatment in order to discharge the treated water to a publicly owned treatment works (POTW). The CSTR process was shown to operate reliably over a five-year demonstration period and operation is still ongoing. In 1999 alone, more than 15,400 lb of ClO_4^- was destroyed at the Thiokol Corporation plant. In general, nutrient, brine, and dilution flowrates were maintained close to target levels during both the pilot-scale and full-scale operations. However, excursions were noted when ClO_4^- levels exceeded 6,000 mg/L and nutrient limiting conditions were experienced.

High temperatures were also found to adversely impact treatment effectiveness and resulted from heat generation caused by an inadequately sized pump, which was later removed from operation. In addition, some plugging or biofouling was experienced in nutrient feed lines and control valves. Over the duration of the study, several optimization steps were taken to select the most cost-effective amendment, to reduce the residence time, to reduce the operating temperature, and to directly feed undiluted nutrients and supplements into the CSTR (ESTCP, 2000).

ARA has also recently completed the installation of a full-scale wastewater treatment system for Hodgdon Powder Company in Herington, Kansas. The CSTR treats wastewater with perchlorate and nitrate concentrations greater than 3,000 mg/L (ARA, 2003).

Table F-1. Selected Ex Situ Biological Treatment Case Study Results

Author	Scale	Reactor Type	Media Type	Reactor Size	HRT	Total Flowrate	Amendments	Initial [Final] ClO$_4^-$ Levels	Initial [Final] Nitrate Levels
ESTCP, 2000	P	CSTR	NA	1,600 gal and 720 gal	18 to 24 hrs	NA	Brewers Yeast Extract	4,000 to 10,000 mg/L [<0.5 mg/L]	346 to 4,622 mg/L
ESTCP, 2000	F	CSTR	NA	1,600 gal and 720 gal	10 to 20 hrs	450 gpm	Carbohydrate By-product	300 to 4,600 mg/L [4 to 400 µg/L]	5,000 mg/L
Hatzinger et al., 2002	P	FBR	GAC	15 ft tall by 20 dia	NA	30 gpm	Ethanol	770 µg/L [<4 µg/L]	33.2 mg/L [<0.4 mg/L]
Hatzinger et al., 2000	F	FBR	GAC	4 Units 22 ft tall by 14 ft dia	12 min	4,000 gpm	Ethanol	4,000 to 6,000 µg/L [<4 µg/L]	6.5 mg/L [<0.4 mg/L]
Guarini, 2002	F	FBR	GAC	1 Unit 21 ft tall and 5 ft dia	NA	50 gpm	Acetic Acid	15,000 µg/L [<4 µg/L]	1.9 mg/L
Togna et al., 2001	L	FBR	GAC	4 L	NA	NA	Acetic Acid and Ethanol	25,000 µg/L [<5 µg/L]	1.9 mg/L
Evans et al., 2002	P	PBR	Plastic and Sand Modules	7 ft tall by 2 ft^2 x-section	NA	1 to 2 gpm	Acetic Acid	75 µg/L [<4 µg/L to 4.8 µg/L]	4.3 mg-N/L [NA]
Perlmutter et al., 2000	P	PBR	Bio-Rings (3/4 to 2")	2,600 gal 5-ft dia and 18 ft tall	60 min	43 gpm	Acetate	23,000 µg/L [<20 µg/L]	NA
Perlmutter et al., 2000	L	PBR	Sand	2.2 gallons	30 to 80 min	20 to 80 mL/min	Acetate	1 to 5 mg/L [<20 µg/L]	NA
Perlmutter et al., 2000	L	PBR	Plastic Beads	2.2 gallons	20 to 130 min	25 to 160 mL/min	Acetate	1 to 5 mg/L [<20 µg/L]	NA
Perlmutter et al., 2000	L	PBR	Bio-Rings (5/8")	2.2 gallons	45 to 300 min	25 to 160 mL/min	Acetate	1 to 5 mg/L [<20 µg/L]	NA
Wallace et al., 1998[a]	L	PBR	Diatomaceous Earth Pellets	1.2 m tall by 7.6 cm in dia	0.5 to 1 hr	NA	Brewers Yeast Extract	1,500 mg/L [<100 mg/L]	NA
Logan and Kim (1998)[a]	L	PBR	Sand	14.2 cm tall	NA	NA	Acetate	20 mg/L [<4 µg/L]	NA
Giblin et al., 2000	L	PBR	Diatomaceous Earth Pellets	120 mL 18 cm tall by 3.5 cm dia	2 hrs	1 mL/min	Hydrogen and Bicarbonate	740 µg/L [<4 µg/L]	NA
Giblin et al., 2000	L	PBR	Diatomaceous Earth Pellets	NA	NA	1 mL/min	Acetate	738 µg/L [<04 µg/L]	NA
Van Ginkel et al., 1998[a]	L	Gas-Lift Reactor	Pumice	NA	6 hrs	NA	Hydrogen Gas	>95% chlorate removal	NA
Rittmann et al., 2002	P	Hollow Fiber	Composite Membrane	13 m^2 surface area	NA	NA	Hydrogen Gas	60 µg/L [3 µg/L]	24 [<0.5 mg/L]

HRT= hydraulic residence time   PBR = packed bed reactor   FBR = fluidized bed reactor
CSTR= continuously stirred tank reactor   NA = not applicable.
(a) Source: Logan, 1998.   (b) Source: Perlmutter et al., 2000.

CSTR Study at Jet Propulsion Laboratory in California

A laboratory-scale study was conducted for JPL to evaluate the use of a CSTR for the treatment of reverse osmosis (RO) rejectates. A simulated RO rejectate was first developed based on the composition of groundwater and the results of previous RO testing at the JPL site. The study demonstrated the rapid development of a perchlorate-reducing culture in a lab-scale CSTR. The microbes were supplied with the same inexpensive food by-product used above in the Thiokol Corporation demonstration project. Although several excursions were experienced during testing, overall it was demonstrated that ClO_4^- could be successfully removed from the surrogate RO brine (at ~10 mg/L) to non-detect levels (<20 μg/L). The excursions or temporary treatment failures during CSTR operation were due primarily to loss of nutrient and/or water flow, pH control problems, and programmable logic control (PLC) or sensor malfunctions. It was estimated in this study that the CSTR process would be able to reduce ClO_4^- within a residence time of 1 to 4 hours (ARA, 2000).

Conclusions

It is not likely that the CSTR configuration alone would be appropriate for ex situ groundwater treatment at JPL. The primary reason is because of the high residence time predicted in the lab-scale study. Another limitation is the potential for high concentrations of organic matter in the system effluent due to both high nutrient loading requirements and suspended cell biomass (Logan, 1998). The treatment train approach with an ion exchange system coupled with a CSTR for brine treatment may be a viable option depending on site-specific economics. The overall advantages and limitations associated with this technology are listed below:

Advantages

- CSTRs can be used to effectively treat very highly contaminated ClO_4^- wastes.

- CSTRs can be used to reduce ClO_4^- in high salinity (>2%) wastewaters.

- The CSTR process is well understood and the system is easily maintained.

- Biological treatment methods are typically less expensive in terms of operation and maintenance costs compared to physical/chemical processes.

- Biological treatment methods typically generate less hazardous waste than physical/chemical processes.

Limitations

- Concentrations above 6,000 to 10,000 mg/L appear to inhibit ClO_4^- reduction by microbes.

- Some other chemicals in wastewater (e.g., isopropyl alcohol) may inhibit ClO_4^- reduction by microbes.

- High organic matter present in CSTR effluent may require additional treatment.

- High residence times limit the ability to treat high flowrates.

- Process is reliable, but upsets can occur from suboptimal electron donor dosing, pH changes, temperature changes, or other conditions.

- Loss of biological activity could interrupt operation for several days.

Packed Bed Reactors

PBRs utilize an attached growth process to stimulate and sustain ClO_4^- degradation. Instead of growing suspended in a liquid as with a CSTR, the biomass in a PBR attaches and grows on a filter media placed inside the reactor. As Table F-1 shows, the filter media can consist of a variety of materials including sand, GAC, plastic rings, and other materials. The filter media is sized and selected to provide a large surface area for contact between the microbes and perchlorate-impacted groundwater and to facilitate flow to obtain the necessary hydraulic residence time. The packed bed also reduces the need for downstream filtration or clarification as used with suspended growth reactors such as the CSTR. However, because of the gradual accumulation of suspended solids and cell biomass in the PBR filter media, the reactor will require periodic backwashing to prevent excessive headlosses (U.S. EPA, 1993). Packed beds are reported to have a tendency for channeling and clogging during long-term operation (Hatzinger et al., 2002; Evans et al., 2002). Backwashing frequencies are typically every 1 to 5 days depending on operational conditions. Backwashing consists of flushing with an air/water wash to slough off excess biomass (U.S. EPA, 1993). After backwashing, there may be some loss of accumulated biomass and additional time may be required to reestablish adequate ClO_4^- reducing performance. Several laboratory scale studies of PBRs have been completed using a variety of filter media and a variety of amendments (see Table F-1). However, to date, only a few field-scale systems appear to have been implemented and reported in the literature as discussed below.

PBR Study at Crafton-Redlands Site in California

A pilot-scale PBR was constructed at the Crafton-Redlands site in Redlands, California where groundwater contains both ClO_4^- and chlorinated volatile organic compounds (VOCs). The chlorinated VOCs were removed using a GAC unit and nitrate and ClO_4^- removal was tested in an up-flow PBR with side-by-side plastic and sand filter media modules. The pilot test was run over a period of 138 days. The up-flow PBR had a cross-sectional area of 2 ft^2 and the reactor height was 7 ft. Acetic acid was selected as the electron donor for this pilot-scale test. The flowrates tested in the PBR ranged from 1 to 2 gpm. Influent ClO_4^- levels were at approximately 75 µg/L, the groundwater was saturated with dissolved oxygen at 8.9 mg/L, and nitrate levels were at 4.3 mg/L. For the plastic packing material, effluent ClO_4^- levels of <4 µg/L were not consistently achieved during the testing period. Backpressures of up to 200 inches of H_2O were observed during the initial two months of testing and this reportedly led to channeling and inadequate residence time in the reactor. Weekly backwashing was then carried out to maintain backpressures at levels less than 100 in H_2O for the duration of the test. Once a backwashing strategy was implemented, a flowrate of 1 gpm resulted in an average effluent ClO_4^- level of less than 4 µg/L, but a flowrate of 2 gpm resulted in an average ClO_4^- effluent level of 4.8 µg/L. It was reported that the sand media was more severely impacted by backpressure and channeling problems and ClO_4^- removal results were not reported for the PBR sand module. Although the study successfully demonstrated that PBRs can obtain ClO_4^- effluent levels less than 4 µg/L, the study concluded that the primary challenge with running a PBR appears to be establishing an effective backwashing strategy to prevent channeling and clogging (Evans, 2002).

PBR Study at McGregor Naval Weapons Industrial Reserve Plant in Texas

ClO_4^- reduction in a PBR was tested at both the bench scale and pilot scale at the Naval Weapons Industrial Reserve Plant (NWIRP) in McGregor, TX. The studies were carried out to demonstrate the feasibility of ClO_4^- reduction in a PBR and to provide data for scale-up of a pump and treat system that would collect groundwater from a cutoff trench at the site boundary. Several parameters were of interest including the optimal water flowrate and media type and the impact of ClO_4^- concentrations and groundwater geochemistry on the bioreactor's performance. The groundwater at NWIRP McGregor contained ClO_4^- at levels ranging from <4 µg/L to 91,000 µg/L.

For the bench-scale tests, five different media were used including 5/8-inch Bio-Rings, 1-inch Bio-Rings, cylindrical plastic pellets, U.S. Silica Sand, and gravel. In addition, three carbon sources were evaluated including citric acid, fructose, and potassium acetate. The bench-scale reactors were first inoculated with activated sludge from the City of McGregor POTW and KJ-1, a cultured perchlorate-reducing microorganism. After the biomass had developed in the reactors, perchlorate-impacted groundwater was passed through the reactors at flowrates between 0.6 and 10 mL/min during Phase I testing and 25 and 160 mL/min during Phase II testing. During the bench-scale testing, initial ClO_4^- concentrations ranged from 30,000 to 100,000 µg/L. The 5/8-inch Bio-Rings were found to be the most effective filter media because they were the least expensive, exhibited more ClO_4^- removal at higher surface loading rates, and were less conducive to clogging than the other media that were tested. Phase II bench-scale testing demonstrated that a PBR of 5/8-inch Bio-Rings, with an acetate amendment, could consistently reduce ClO_4^- to less than 20 µg/L (the detection limit due to high nutrient levels). Reliable reduction was achieved at flowrates up to 160 mL/min or a surface loading rate of 4.2×10^{-4} gpm/ft^2. Hydraulic residence times ranged from 45 to 300 minutes. By comparison, reliable reduction with sand was achieved only at flowrates up to 80 mL/min, which corresponds to a much lower surface loading rate of 1.0×10^{-5} gpm/ft^2.

Based on the above results, a 43 gpm pilot-scale PBR was constructed on site and consisted of a 5-ft-diameter, 18-ft-tall bioreactor filled with 2-inch and ¾-inch Bio-Pac media. In order to limit the amount of wastewater generated during the test, the PBR was operated as a closed-loop system or with continuous recirculation of a finite amount of water. The pilot-scale test was run over a 28-day period. After inoculation, it took approximately one week for the biomass to develop in the bioreactor. ClO_4^- influent levels ranged from approximately 7,000 to 23,000 µg/L. The PBR was able to consistently reduce ClO_4^- levels down to less than 20 µg/L. The detection limit was elevated above the 4 µg/L laboratory method detection limit because of the high total dissolved solids (TDS) in the groundwater which ranged from 2,850 mg/L at the start to >5,000 mg/L at the end of the test. The increasingly high TDS levels were due primarily to the test configuration, which called for continuous recirculation of the treated water. The pilot-scale test demonstrated that ClO_4^- could be effectively reduced at a rate of 12 lb/day or a surface loading rate of 1.5×10^{-3} gpm/ft^2. The retention time was measured at 60 minutes. No major excursions were noted over the 28 days of operation and no observations of clogging or channeling were discussed in the literature. Despite the successful treatment demonstration, the pilot-scale PBR system was not taken to full-scale at NWIRP McGregor. Instead, an innovative in situ permeable reactive barrier was installed to prevent off-site migration of ClO_4^- as opposed to the previously planned groundwater pump and treat system (Perlmutter et al., 2000).

PBR Lab Studies at Jet Propulsion Laboratory in California

The lab-scale study for JPL consisted of PBR column studies to demonstrate the feasibility of ClO_4^- reduction in both groundwater and simulated RO rejectates. The Plexiglas^{TM} column used in the study was 13.5 cm in diameter and 21.4 cm in height with a total volume of 3,062 mL. Celite was used as the

filter media. The test column was inoculated with a cultured perchlorate-reducing microbe called *perclace* identified previously by Herman and Frankenberger (1999). Acetate was used as the carbon source during these tests. Each column test lasted approximately four weeks. Although some excursions occurred due to periodic failures of the acetate pump and a temporary lack of electron donor supply, treatment before and after these brief upset conditions was effective for both groundwater and the primary RO rejectate. It was demonstrated that the PBR system was able to reduce ClO_4^- in JPL groundwater from 800 µg/L to non-detect (<4 µg/L) at a residence time as low as 0.3 hour. In addition, the PBR reduced ClO_4^- in the primary RO rejectate from 5 mg/L to non-detect (<4 µg/L) with a residence time of less than 0.8 hour. Secondary RO rejectate could not be treated to non-detect levels, which indicated that *perclace* was inhibited at the higher ClO_4^- influent levels. However, 90% removal was achieved (from 10 mg/L to 0.2 mg/L) during a 2.1 hr residence time. Other results from the laboratory tests indicated that nitrate was effectively removed in all three waste streams, there was no need for nitrogen addition, and sulfate reduction did not occur in any of the column tests (Losi et al., 2001).

PBR Field Studies at Jet Propulsion Laboratory in California

Several field-scale PBR configurations were tested at NASA JPL during a phased pilot program as discussed below:

Phase I was conducted in the spring of 2001. During this phase, three 6 gpm PBR reactor configurations were field tested at the site. The pilot system consisted of three PBRs packed with Celite® R-633, which is a diatomaceous earth product with a sand-like consistency and relatively high surface area. The three test PBRs were set up in parallel. Each reactor was associated with a different combination of biological inoculum and carbon source. These combinations included *perclace* with acetate, food waste/compost with ethanol, and cultures isolated from JPL with acetate. The reactors were first operated in recycle mode for several weeks, while discharge approval was negotiated. Upon initiation of forward flow mode, the pilot-scale reactors were shown to successfully reduced ClO_4^- concentrations in groundwater from 0.42 mg/L to less than 4 µg/L. However, after less than one week of operation the reactors experienced channeling and plugging and perchlorate breakthrough was observed.

The Phase II testing occurred in the summer and fall of 2002. The Phase II pilot system consisted of two bioreactors in series packed with Hydroxyl-PAC® high-density polyethylene media and two bioreactors in series packed with polyethylene sponge scrubbers impregnated with Celite® R-635 pellets. The reactors were filled only about two-thirds full to allow for movement and suspension of the media. This reactor configuration was referred to as a dynamic suspended bed reactor (DSBR). The DSBR was expected to provide improved flow characteristics by using different media with less surface area and greater pore volume than used in Phase I testing. The extra space in the vessels allowed for bed expansion unlike the PBRs tested previously. The substrate of sodium acetate was added at a concentration of 300 mg/L. Nutrients were added at 1.0 and 0.9 mg/L as hydrogen phosphate (HPO_4-P) and ammonium nitrogen (NH_4-N), respectively. Phase II tests showed that both packing materials showed promise as media for ClO_4^- reduction, but the reactor with Hydroxyl-PAC® media had slightly better overall performance. The reactor inoculated with *perclace* was found to perform better than the reactor with the JPL isolates for ClO_4^- removal. NO_3^- was reduced to non-detectable levels by both reactors throughout the test. However, the perchlorate removal rates were only at 70% to 80% for influent concentrations from 1.5 up to 10.5 mg/L.

Conclusions

Based on the results of several laboratory and full-scale studies, it is clear that PBRs have a high potential for channeling and clogging and that this adversely impacts full-scale process effectiveness, reliability,

and control. PBRs are also reported to handle lower ClO_4^- loading rates than FBRs (Harding Lawson Associates, 1999). In addition, because of limited field-scale experience with these systems and lack of a dedicated commercial vendor, it is unlikely that a PBR configuration would be appropriate for ex situ groundwater treatment at JPL at this time. The overall advantages and limitations associated with this technology are listed below:

Advantages

- PBRs have much lower residence time requirements than CSTRs due to the advantages of attached growth mechanisms and increased biofilm surface area.

- PBR pumping requirements and costs are less than FBRs because lower total flowrates and recycle rates can be used without the need for fluidized media.

- Biological treatment methods are typically less expensive in terms of operation and maintenance costs compared to physical/chemical processes.

- Biological treatment methods typically generate less hazardous waste than physical/chemical processes.

Limitations

- PBRs appear to be prone to channeling and clogging, and frequent backwashing may be needed.

- Frequent backwashing may impair the ability of the biomass to degrade ClO_4^-.

- Process is reliable, but upsets can occur from suboptimal electron donor dosing, pH changes, temperature changes, or other conditions.

- Loss of biological activity could interrupt operation for several days.

Fluidized Bed Reactor

FBRs are similar to PBRs except that the influent flowrate must be high enough to produce a fluidized bed of media. Fluidization means that the media particles are suspended and not in contact with other particles. Fluidization increases the specific surface area available for microbial growth and therefore increases the efficiency of ClO_4^- reduction per unit volume of the reactor. In an FBR, the specific surface area available for microbial growth is 244 to 305 m^2/m^3 of reactor volume compared to approximately 91 m^2/m^3 in a downflow PBR configuration. This advantage can be used to size smaller bioreactors and/or to reduce hydraulic residence times while still obtaining effective ClO_4^- reduction (U.S. EPA, 1993). A more detailed discussion of the configuration and operation of FBR systems will be provided in the three case studies provided below.

FBR Case Study at Aerojet Facility in California

Since 1997, the Aerojet General Corporation has tested and operated both pilot-scale and full-scale FBRs for ClO_4^- removal as part of the groundwater remediation efforts at its facility in Rancho Cordova, California. The constituents of concern in groundwater at the Aerojet site also include chlorinated solvents and other VOCs. An extensive treatability testing program was conducted on the FBR system at Aerojet to demonstrate to the State of California DHS that potable water can be consistently produced by

the selected treatment train. The treatment train consisted of biological treatment, air stripping, filtration, ultraviolet oxidation, granular media filtration, GAC, and chlorine disinfection (Clark et al., 2001). The treated groundwater is then discharged directly to surface water. In April of 2002, the DHS reviewed the results of the Aerojet treatability testing program and accepted the use of biological treatment to remove or reduce perchlorate from source water that might be used as a potable water supply (DHS, 2002). The results of the Aerojet site pilot-scale and full-scale treatability tests with FBRs are discussed below.

Several laboratory pilot-scale experiments were conducted to optimize the removal of ClO_4^- from groundwater using the FBR process through filter media selection, electron donor selection, and other testing parameters. The filter media tested included GAC with a particle size range from 0.9 to 1.4 mm and sand with a particle size range of 0.3 to 0.6 mm. The electron donors tested included ethanol, methanol, and an ethanol/methanol mixture. The laboratory study was conducted over a four-month period. Each laboratory FBR consisted of a 5-cm-diameter glass column, which was approximately 90 cm in length. Other equipment included the recycle/fluidization pump, feed and effluent pumps, various storage tanks, dissolved oxygen sensors, and an automatic pH control device. The FBRs were operated at room temperature (i.e., 20 to 25°C) and were maintained near a neutral pH of 7.0 to 7.5. A total influent pumping rate of approximately 700 mL/min was needed to maintain fluidization of the media in each reactor. Influent ClO_4^- concentrations ranged from 13 to 28 mg/L during testing. Nitrate levels were at approximately 1.5 mg/L. Dissolved oxygen levels ranged from 1 mg/L to 8 mg/L and were varied during the test to determine the potential impact of pretreatment with air stripping on bioreactor performance. The columns were inoculated with biological solids from a municipal wastewater anaerobic digester in order to develop a perchlorate-reducing biomass. After approximately 34 days of operation, biomass buildup was significant enough to result in more than $0.7 \ kg/m^3/day$ of ClO_4^- removal in both the GAC and the sand-based FBRs with ethanol as the electron donor. The sand-based FBR with methanol as the only electron donor did not show effective ClO_4^- removal. The conclusions of the pilot test were that a GAC based FBR could achieve a higher level of ClO_4^- reduction than a sand-based FBR. Granular activated carbon- and sand-based FBRs with only methanol as the electron donor were not effective. However, a high level of ClO_4^- reduction could be achieved in both types of reactors with an ethanol/methanol mixture (Sutton and Greene, 1999).

After the laboratory studies discussed above, further testing was completed during a Phase I treatability test using a 30-gpm FBR pilot plant system installed at the site. The objectives of the Phase I testing were as follows: (1) to evaluate lower ClO_4^- influent levels, (2) to evaluate higher nitrate levels, (3) to demonstrate that ClO_4^- effluent levels of <4 µg/L were achievable, (4) to identify a different source of microorganisms, and (5) to evaluate the potability of the treated water. The Phase I pilot-scale test was able to demonstrate the consistent reduction of ClO_4^- from levels between 50 and 100 µg/L in the influent to less than the detection limit of 4 µg/L in the effluent. The system was also able to reduce nitrate levels from 5 to 6 mg/L in the influent to below the detection limit of 0.1 mg/L in the effluent. The pilot plant was inoculated with perchlorate-reducing microbes obtained from food processing industry sludge. No fecal coliform or other human pathogens were identified in the treatment system effluent. The treated water was also analyzed for regulated drinking water parameters and it was determined that additional treatment would be needed to meet disinfection and filtration requirements (Harding Lawson Associates, 1999).

Based on parameters from the laboratory and field pilot-scale studies, a full-scale FBR system was installed at the Aerojet site and has been operating since approximately 1998. Currently, extracted and treated groundwater is being discharged to surface water, but DHS approval has been received for potable water use (DHS, 2002). A Phase II treatability study was performed for more than eight months using this full-scale FBR system in order to further test the reliability of the biological treatment process and to test the entire drinking water treatment train as described previously. The primary objectives of the Phase II testing were as follows: (1) to confirm destruction and removal efficiencies of each unit, (2) to establish

optimal operating parameters for each unit, (3) to collect data to support potable water use, and (4) to collect data for full-scale drinking water treatment plant construction and operation.

The existing pump and treat system at the Aerojet site includes four FBR units, but only one was used during Phase II treatability testing. Each individual unit is rated for up to 1,800 gpm of flow and is 14 ft in diameter and 22 ft tall. GAC was selected as the filter media and ethanol as the electron donor. Fluidization of the reactor media is achieved by passing the influent up through the bioreactor. A fluid distribution system or network of nozzles ensures a uniform upflow velocity across the bottom of the bed. The flowrate must be high enough to achieve at least a 25% to 30% expansion of the bed. At the Aerojet site, a total flowrate of 1,800 gpm in each reactor is needed to achieve fluidization of the media and to obtain a target bed expansion of 33% or a total bed height of 12 ft. At this total flowrate, the hydraulic residence time for each reactor is 14 minutes. The total flow through the FBR consists of both the recycle flow of treated water and the forward flow of untreated groundwater. After startup of the Aerojet system, the forward flow was increased from 240 gpm to approximately 1,400 gpm for the last four months of the Phase II treatability study.

In general, as biomass continues to grow on the FBR media, the particle surface area will increase and the media particles will become less dense. The lowest density particles with the highest attached biomass will then move up to the top of the FBR causing further bed expansion. For this reason, a biomass control system is used at the top of each reactor to remove the excess biomass and to maintain the target bed height. Two different biomass control systems were used on the Aerojet FBR unit during Phase II testing, but some problems were experienced obtaining adequate separation of filter media and sheared biomass. The first biomass control system used consisted primarily of an eductor-type, bed-height limiter that sheared biomass from the GAC and then discharged the clean carbon and sheared biomass back into the reactor. The clean carbon sinks to the bottom of the reactor and the sheared biomass is carried out of the bioreactor in the effluent. A second control device was installed within the bed itself to minimize the overgrowth of filamentous bacteria. Proper biomass control is important as overloading of the biomass into the effluent was shown to cause treatment problems downstream with operation of the multimedia filter (Harding ESE, 2001).

Despite some issues with optimal biomass control, the FBR unit was demonstrated to operate with acceptable stability in removing ClO_4^- from site groundwater. ClO_4^- influent levels ranged from 2 to 7 mg/L. Dissolved oxygen influent levels ranged from 4 to 6.5 mg/L and nitrate influent levels were relatively constant at 1.6 mg/L. After a three-week acclimation period for biomass growth, ClO_4^- was consistently removed to non-detect at <4 μg/L for the duration of the Phase II testing. Dissolved oxygen levels in the effluent ranged from 0.01 to 0.25 mg/L, but were usually less than 0.1 mg/L. Nitrate was consistently removed to non-detect at 11 μg/L. The only excursions that occurred were caused by forced ethanol-limiting conditions that were brought about during system tests to determine the optimal ethanol dosage for full-scale operation. All four bioreactors at the Aerojet site have continued to operate without excursions or treatment failures as part of the existing pump and treat system at Operable Unit 3. Recommendations for future improvements to the system included adjustments to the biomass control system and the development of a more effective means of on-line monitoring and process control to automate ethanol dosing to the bioreactor (Clark et al., 2001).

FBR Case Study at Longhorn Army Ammunition Plant in Texas

A 50-gpm FBR system was installed at the Longhorn Army Ammunition Plant (LHAAP) in Texas to remove ClO_4^- from groundwater extracted by a pre-existing pump and treat system. The pump and treat system had been originally designed to treat only VOCs and metals. First, a laboratory treatability study was carried out to provide key parameters for full-scale FBR design and to confirm the effectiveness of biological treatment with site groundwater. Acetic acid and ethanol were both tested for their ability to

promote the reduction of ClO_4^- in groundwater from the site. The groundwater used in the study contained approximately 14.7 mg/L of ClO_4^-, 1.9 mg/L of nitrate, and 3.8 mg/L of dissolved oxygen. Granular activated carbon was used as the filter media in the lab-scale FBR and the test reactor was inoculated with biomass and carbon from another perchlorate-reducing laboratory FBR. ClO_4^- removal was observed in the test bioreactor within a few days of inoculation. The project objective was to treat the groundwater to meet the LHAAP wastewater discharge permit limit of 350 µg/L for ClO_4^-. However, during the majority of the laboratory testing, the ClO_4^- effluent levels were below the detection limit of <5 µg/L. Both acetic acid and ethanol were found to promote ClO_4^- reduction in LHAAP groundwater. Based on the success of the laboratory study, a full-scale, 50 gpm FBR system filled with granular activated carbon was installed at the site. The FBR system consisted primarily of the reactor vessel (5 ft in diameter and 21 ft tall), fluidization and influent pumps, flow distribution system, chemical feed system, two biomass separation systems to control bed height from the top, and a third in-bed media cleaning system. Acetic acid was selected as the electron donor (Togna et al., 2001). After more than 250 days of full-scale operation, the ClO_4^- effluent concentrations have been consistently below the detection limit of <4 µg/L (Guarini, 2002).

FBR Case Study at Jet Propulsion Laboratory in California

An FBR field pilot test was conducted over a 100-day period at JPL in order to evaluate system performance under site-specific conditions and to provide data to size and cost a full-scale system. The 30-gpm FBR system consisted primarily of a reactor vessel (20 ft in diameter and 15 ft tall), which was filled with granular activated carbon as the filter media. Other components included the fluidization system, biomass control device, and various tanks, pumps, and controls for the addition of electron donor and nutrients, and a system for pH control. In addition, a granular activated carbon system was used to remove VOCs prior to the FBR influent. A post-aeration tank was also supplied to aerate the effluent of the FBR to degrade any excess ethanol prior to discharge. A 9% solution of ethanol was used as the electron donor, along with small amounts of nitrogen and phosphorous as nutrients to promote microbial growth.

The pilot-scale reactor was first inoculated with granular activated carbon from the Aerojet site. After the inoculation, site groundwater was run through the system in a flow forward mode for 27 days and a recycle mode for 22 days. During the recycling period, ethanol and nutrients were added to sustain biological growth and oxygen was periodically added to supply the microbes with an alternate electron acceptor prior to the initiation of the FBR pilot test. After approval to discharge the treated effluent was received, the test was returned to flow forward operation and a 52-day pilot test was initiated. During the test, the maximum flowrate achieved from the groundwater extraction pilot well was 5.2 gpm. This was combined with recycle flow to maintain a total flow of 30 gpm for fluidization of the filter media.

After only three days of operation in this mode, ClO_4^- levels in the influent were reduced from 770 µg/L to <4 µg/L in the effluent and nitrate levels were reduced from 7.5 mg/L in the influent to <0.1 mg/L in the effluent. Over the duration of the test, the average influent ClO_4^- level was 310 µg/L and the maximum was 1.1 mg/L. The average nitrate influent level was 6.11 mg/L. The average ethanol feed rate was 3.9 mL/min and was based primarily on the nitrate loading requirements. No unplanned excursions were experienced during the operation of the 52-day FBR pilot test. The system was briefly forced into nutrient-limiting conditions to demonstrate that biological reduction was the primary removal mechanism for ClO_4^- reduction. The elimination of the nutrient supply resulted in gradually increasing levels of ClO_4^- in the effluent from <4 µg/L up to 240 µg/L and nitrate from 0.4 mg/L to 3.32 mg/L over a 10-day period. After this brief test, the ethanol feed rate was returned to the target level and the ClO_4^- effluent levels returned to <4 µg/L and nitrate levels to 0.4 mg/L within one day (Hatzinger et al., 2002). During the pilot test, biomass film growth was managed manually and no problems were reported with

maintaining a stable biomass, or in controlling the bed height or biofilm growth. The pilot test demonstrated that FBR could be successfully implemented at JPL to treat both nitrate and ClO_4^- (U.S. Filter, 2001).

Conclusions

As reported in the GWRTAC report, FBRs are the most commonly studied and/or implemented ex situ biological treatment technology (GWRTAC, 2001). Because FBRs have been successfully implemented at the full-scale at several sites and at the pilot-scale at JPL, it appears that FBR would be the most appropriate reactor configuration for ex situ biological treatment to be implemented as part of an expanded treatability study. The overall advantages and limitations associated with this technology are provided below:

Advantages

- FBRs have a larger surface area for biomass growth compared to PBRs.

- Higher biomass in FBRs allows reactors to have a smaller volume and footprint compared to CSTRs and PBRs.

- Higher biomass means shorter hydraulic residence times with FBRs compared to CSTRs and PBRs.

- FBR operation is more efficient over the long-term compared to PBRs because fluidization and continuous biomass control minimizes clogging and/or channeling in the reactor.

- Recycling of effluent can lead to more stable influent conditions and better bioreactor performance.

- The FBR technology has been successfully commercialized (e.g., at least two full-scale systems are currently in operation).

- Biological treatment methods are typically less expensive in terms of operation and maintenance costs compared to physical/chemical processes.

- Biological treatment methods typically generate less hazardous waste than physical/chemical processes.

Limitations

- FBRs are reportedly more expensive to build and operate compared to PBRs.

- High recycle rates or total flowrates are required to keep the filter media fluidized and this can increase pumping capital and electricity costs.

- Operational problems have been reported in the literature related to bed media loss, bed height control, and the release of biomass into the effluent.

- Process is reliable, but upsets can occur from suboptimal electron donor dosing, pH changes, temperature changes, or other conditions.

- Loss of biological activity could interrupt operation for several days.

Innovative Amendments and Reactor Types

Several novel amendments and/or bioreactor types have been proposed in the literature and by various vendors. O'Niell et al. (1999) discusses the use of microbial mat and algae bioreactors for ClO_4^- reduction. Eco-Mat Incorporated has developed an attached growth reactor that uses a media called Eco-Link. This sponge like material provides a large surface area for naturally occurring denitrifying bacteria to live and grow. This technology is currently used at the full-scale for nitrate removal in aquariums and at the pilot-scale for ClO_4^- removal at groundwater remediation sites. Batista and Liu discuss the use of a microporous membrane reactor where ClO_4^- diffuses across the membrane and is reduced by an immobilized biofilm growing on the membrane (Batista and Liu, 2001). In addition, a number of recent studies have focused on the benefits of using hydrogen as an electron donor for ClO_4^- reduction (Logan, 1998; Van Ginkel et al., 1998; Giblin et al., 2000; and Rittmann et al., 2002).

The use of a PBR configuration for hydrogen delivery has been tested, but more novel bioreactor configurations have also been proposed including a gas-lift reactor with pumice filter media and a hollow-fiber membrane biofilm reactor (HFMBfR). Giblin et al. was able to demonstrate the reduction of ClO_4^- from 0.740 mg/L in the influent to <4 µg/L in the effluent with hydrogen as the electron donor. However, several problems were encountered with this configuration including non-uniform distribution of biomass in the column, unstable pH conditions, and limited delivery of hydrogen to the bacteria (Giblin et al., 2000). In a gas-lift reactor filled with pumice particles, Van Ginkel et al. (1998) was able to demonstrate nearly complete removal of ClO_4^-, chlorate, and chlorite at residence times varying from 0.2 to 120 minutes (as reported by Logan, 1998). Rittmann et al. has demonstrated successful removal of ClO_4^- in a pilot-scale HFMBfR at the La Puenta, California Superfund site. This novel reactor configuration uses a composite membrane, which supports the growth of a thin biofilm across the surface. The pilot modules at the La Puenta site each contained 7,000 fibers with approximately 13 m^2 of biofilm surface area. The reactor has been shown to be 100% efficient in supplying hydrogen for the reduction of oxygen, nitrate, and ClO_4^-. ClO_4^- was reduced from 60 µg/L in the influent to 3 µg/L in the effluent and nitrate was reduced from 24 mg/L in the influent to <0.5 mg/L in the effluent (Rittman et al., 2002). The primary advantages and limitations associated with the use of hydrogen gas bioreactors in a variety of configurations are as follows:

Advantages

- Hydrogen is the least expensive of the electron donor alternatives.

- Biofouling is minimized because hydrogen does not promote vigorous overgrowth of biomass.

- Hydrogen is nontoxic.

- No residual hydrogen is left in the treated water.

Limitations

- Hydrogen does not promote cell biomass growth, so sustainability of removal rates over time is uncertain.

- Only one pilot-scale field application of the hollow-fiber membrane biofilm reactor has been completed to date.

In Situ Bioremediation

Several authors have noted the potential for bioremediation to effect the in situ treatment of perchlorate-impacted soil and groundwater including Hatzinger et al. (2002), Logan (2001), and others. In situ bioremediation can be used to achieve source area treatment and thereby decrease or eliminate ClO_4^- dissolution into the groundwater over the long term. In situ bioremediation can also be implemented in a biobarrier application to prevent off-site migration of perchlorate-contaminated groundwater. Numerous microcosm studies have been completed that demonstrate the successful biodegradation of ClO_4^- using a variety of electron donor amendments (see Table F-2). In addition, perchlorate-reducing microbes have been shown to be present in a wide variety of environments including pristine and hydrocarbon-contaminated soils, aquatic sediments, paper mill waste sludge, and farm animal waste lagoons (Gingras and Batista, 2002). Despite several successful laboratory studies, only a few in situ bioremediation field-scale applications have been completed to date for ClO_4^- remediation. Based on the results from these initial field tests, the primary challenge appears to be adequate delivery of the electron donor to the subsurface over large source areas and/or in groundwater plumes located at depths greater than 100 ft bgs (Hatzinger, 2002).

In Situ Bioremediation Amendments

Although ClO_4^- is readily biodegraded in laboratory microcosm studies, this process may be limited in the field under "natural" conditions for several reasons. This includes the lack of ClO_4^- reducing microbes at a given site, little to no carbon substrate for microbial growth, high dissolved oxygen levels in groundwater, and/or the presence of other compounds, such as nitrate which are preferentially degraded (Logan, 2001 and Zhang et al., 2001).

Some of these factors may be overcome through the injection of bioremediation amendments such as alcohols, fatty acids, edible oils, sugars, or other substances and/or through the introduction of cultured, perchlorate-reducing microbes (i.e., bioaugmentation). In general, bioaugmentation is not necessary because most perchlorate-contaminated sites have been demonstrated to contain indigenous populations of ClO_4^- reducing microbes and bioaugmentation has not been demonstrated to substantially increase ClO_4^- degradation rates in microcosm studies (Coates, 2000). As shown in Table F-2, several amendments have been tested for their ability to promote the biodegradation of ClO_4^-. In general, the amendment is used by the microorganisms to build cell biomass and acts as an electron donor through oxidation to carbon dioxide and water. ClO_4^- acts as the electron acceptor and is sequentially reduced to chlorate, chlorite, and then chloride and oxygen (Cox, 2001). Several confounding factors or parameters can inhibit this process including the presence of oxygen and nitrate, which compete with ClO_4^- as electron acceptors. Low pH (e.g., less than 5) and high salinity levels have also been reported to decrease ClO_4^- biodegradation rates (Hatzinger, 2000; Zhang et al., 2001).

The selection of the most appropriate amendment should be site-specific and is typically based on the biodegradation rates measured in microcosm studies. However, several other issues must be considered

in the selection of an amendment including cost, supply, presence of impurities or nuisance compounds (e.g., sulfur in molasses), and the ability to obtain permission for injection of the substance into the subsurface. Another consideration is whether a soluble amendment (e.g., acetate) is appropriate or an insoluble amendment (e.g., vegetable oil). Several amendments were tested during the JPL microcosm study including acetate, benzoate, ethanol, lactate, hydrogen, methanol, molasses, propane, sucrose, and yeast extract with ethanol. Table F-2 presents the overall results from this study, along with a summary of amendments tested for use during other in situ bioremediation projects. The JPL study demonstrated that acetate, lactate, ethanol, molasses, and yeast extract were the most promising amendments and achieved rapid biodegradation in less than 14 days. The microcosms with these amendments all showed the reduction of ClO_4^- from 310 µg/L to non-detect (<4 µg/L) levels in a rapid time frame. The microcosm study at JPL also demonstrated that indigenous bacteria at the site are capable of reducing ClO_4^- and identified the microbes cultured from the site as *Dechlorosoma suillum* strain JPLRND (Hatzinger et al., 2002).

In Situ Bioremediation Delivery Mechanisms

Several different methods have been proposed in the literature for the delivery of electron donor to the subsurface including passive, semipassive, and active injection scenarios. A brief summary of these methods is provided below.

Passive delivery methods rely upon the natural groundwater gradient and dissolution and dispersion to deliver the electron donor into the subsurface. Passive strategies include permeable reactive barriers or the placement of a slow release compound (e.g., vegetable oil or polylactate) in an array of unpumped wells (ITRC, 1998). As discussed below, a permeable reactive barrier filled with gravel and organic amendments (compost and cottonseed meal) was installed at NWIRP McGregor to intercept the seepage of perchlorate-contaminated groundwater into a nearby stream. Depth to groundwater at this site was less than 6 ft below ground surface (bgs) (Perlmutter et al., 2000). In general, permeable reactive barriers are best suited to shallow groundwater sites because of the need to key the barrier into bedrock or a substantial impermeable clay layer and the limits of conventional trenching methods. This technology would be impractical to implement at JPL because the depth to bedrock at JPL is more than 1,000 ft in some areas. Although the use of hydrogen release compound (HRC), a slow release polylactate, has been demonstrated in laboratory studies to degrade ClO_4^- (Logan et al., 2000), no field-scale applications for ClO_4^- treatment were identified. However, numerous field-scale applications of HRC for chlorinated VOC removal exist in the literature (Koenigsberg and Ward, 2000). Vegetable oil has been proposed for ClO_4^- reduction by several authors including Hunter (2001). The GWRTAC report mentions that a pilot-scale test is planned for ClO_4^- plume treatment with edible oils at Edwards Air Force Base, but the results were listed as still pending (GWRTAC, 2001). Also, a radial biobarrier pilot test with the injection of canola oil and oleate was planned at the Aerojet Facility in California. The anticipated radius of influence was 10 ft around each delivery well (Geosyntec, 2001). In general, slow release compounds are more economical for the treatment of shallow aquifers (<100 ft bgs) because of the tight spacing needed for the introduction of viscous or insoluble substances into the subsurface (Hatzinger, 2002).

Table F-2. Examples of In Situ Bioremediation Amendments for ClO$_4^-$ Reduction

Author	Scale	Amendment(s)	Initial [Final] ClO$_4^-$ Levels	Initial [Final] Nitrate Levels	Initial [Final] O$_2$ Levels	pH	Comment
Hatzinger et al., 2000 and 2002	L	Acetate, Lactate, Ethanol, Molasses, Yeast Extract	310 µg/L [<5 µg/L]	18.6 mg/L	2.6 mg/L	7.6	JPL microcosm results indicate rapid ClO$_4^-$ biodegradation (<14 days to ND).
Hatzinger et al., 2000 and 2002	L	Hydrogen, Propane, Methanol, Sucrose	310 µg/L [<5 µg/L]	18.6 mg/L	2.6 mg/L	7.6	JPL microcosm results indicate slow ClO$_4^-$ biodegradation rate (~21 days to ND).
Zhang et al., 2001	L	Lactate	100 mg/L [ND to 60 mg/L]	13 to 65 mg/L [NA]	NA	NA	ClO$_4^-$ degradation rate 33 to 187 ug/day
McMaster and Cox, 2001	P	Acetate	10 to 15 mg/L [<4 µg/L]	5 mg/L [NA]	2 to 5 mg/L [~ 1mg/L]	NA	Closed loop system. ClO$_4^-$ Half-Life 0.2 to 1.8 days. Other substrates tested molasses, canola oil
Hunter, 2001 and 2002	L	Soybean Oil	20 mg/L [0.070 mg/L]	20 mg/L [ND]	NA	NA	>99% removed between 5th and 18th weeks.
Perlmutter et al., 2001	L	Acetate, Molasses	1,500 mg/L [<4 µg/L]	NA	NA	NA	ClO$_4^-$ removal rates from 200 to 600 mg/L/day.
Perlmutter et al., 2001	L	Fruit Juice, Compost	1,500 mg/L [NA]	NA	NA	NA	None. Fermentation and lack of organic carbon inhibited degradation.
Arcadis Geraghty and Miller, 2001	P	Corn Syrup	81 to 190 µg/L [18 to 200 µg/L]	13 mg/L	0 to 18.7 mg/L	4.6 to 8.3	Injection with downgradient extraction (~400 ft). Also considered molasses, cheese whey.
Logan et al., 2000	L	Hydrogen Release Compound	165 mg/L [<4 µg/L]	NA	NA	NA	Cell growth rates ranged from 3 to 35 hrs
Geosyntec, 2002	P	Calcium Magnesium Acetate	6 to 8 mg/L [5 to 6 mg/L]	NA	5 mg/L [5 to 6 mg/L]	NA	Vadose zone flushing and groundwater treatment. No treatment effected.
Geosyntec, 2001	L/P	Canola Oil and Oleate	100 mg/L [<18 µg/L]	NA	NA	NA	Radial biobarrier. Half-life 2.8 days with canola oil and 5.2 days with oleate.

Semipassive delivery strategies consist primarily of injection-only configurations. These methods rely upon continuous or periodic forced injection of the electron donor into one well or an array of wells. Semipassive systems are best suited to the reduction of chemical concentrations in low-concentration plumes and/or to act as a biobarrier or "polishing step" for other remediation methods. Semipassive systems do not provide hydraulic containment and may produce localized mounding depending upon the injection strategy (ITRC, 1998). Another type of semipassive system is gas injection. Hydrogen, propane, or other gasses can be injected into a contaminated aquifer (typically using a horizontal well configuration). Although, no field-scale applications of gas injection for ClO_4^- plume treatment were identified, this strategy has been used at several sites for chlorinated VOC plume treatment. For example, methane and air were injected at a rate of 250 to 300 cubic ft per minute in a horizontal well to effect chlorinated VOC removal in groundwater at the Former Naval Ammunition Depot in Hastings, Nebraska (ITRC, 1998).

Active methods involve both injection and extraction to promote mixing and delivery of the electron donor in the aquifer. Active delivery methods include dual vertical well recirculation, dual horizontal well recirculation, single vertical well recirculation, and other approaches. Typically, a system will consist of a row of upgradient vertical injection wells paired with a row of vertical downgradient extraction wells. Groundwater is extracted from the downgradient wells, the electron donor is added, and the groundwater is reinjected in the upgradient wells. The injection and extraction wells are most often oriented perpendicular to the natural groundwater gradient, but can be rotated at some angle to allow for the flow of upgradient groundwater through the treatment zone. Vertical wells are the most frequently used, but horizontal wells and trenches can also be employed for injection or extraction. The recirculation of groundwater should promote the mixing of the amendment within the aquifer and will allow for multiple passes of the contaminated groundwater through the treatment zone. Active delivery mechanisms are best suited for treating high-concentration plumes or source areas and can also be designed to provide for hydraulic containment (ITRC, 1998). As discussed below, active delivery systems have been used at Aerojet in Rancho Cordova, California for ClO_4^- plume treatment at depths of 200 ft bgs (McMaster and Cox, 2001; Cox, 2002). In addition, McCarty et al. (1998) has proposed an innovative recirculation cell configuration for the treatment of a chlorinated VOC groundwater plume. The system is designed so that groundwater is never brought to the surface. Instead, a subsurface system is used in which two vertical wells with extraction and injection ports separated by an aquitard are used to recirculate groundwater between two different aquifer layers (McCarty et al., 1998).

Permeable Reactive Barrier Case Study at NWIRP McGregor

An interim stabilization action was needed at NWIRP in McGregor, TX in order to control and prevent off-site migration of perchlorate-contaminated groundwater. ClO_4^- was present in surface water at the site boundary at levels up to 5,600 μg/L and in groundwater at levels up to 91,000 μg/L. First, a high permeability cutoff and collection trench was installed at the site in order to intercept groundwater prior to off-site migration or seepage into nearby surface water. The initial remedial action plan called for pumping and ex situ biological treatment of the collected groundwater. However, after several successful bench-scale tests, an in situ bioremediation approach was selected instead. A permeable reactive barrier was determined to be feasible at this site because the water table at the site was only 6 ft bgs and the perchlorate-impacted portion of the aquifer was only 10 to 25 ft thick. The existing cutoff and collection trench originally designed for a pump and treat application was then modified. The trench was backfilled with gravel, organic material (e.g., compost and cottonseed meal), and granular activated carbon. The organic material was added to provide a carbon or electron donor source for microbes to reduce ClO_4^- as groundwater moved through the barrier.

First, a bench-scale study was completed to demonstrate the potential effectiveness of in situ bioremediation with a variety of carbon source material. The media tested included compost, canola oil-

coated wood shavings, cottonseed meal, and granular activated carbon. These materials were mixed with gravel, so that the barrier would remain permeable. The gravel content ranged from 90% to 95% of the total media volume. The bench-scale tests involved the use of four Plexiglass^{TM} bioreactors, each 6 inches in diameter and 18 inches tall. The bioreactors were inoculated with microbes from the local POTW. Flowrates ranged from 2 to 8 mL/min during the tests. Compost and cottonseed meal bioreactors performed the best with >99% and >98% ClO_4^- removal, respectively. In addition, both of these materials contain high levels of nitrogen, which is a key nutrient for microbial growth. Canola-oil-coated wood shavings removed >98% of the ClO_4^- in the influent stream. However, it was determined that the lower levels of nitrogen and phosphorous in the canola oil would make it less effective over the long term compared to compost and cottonseed. Influent ClO_4^- levels in the compost, cottonseed meal, and canola oil reactors ranged from 2,500 µg/L to 8,500 µg/L. Effluent ClO_4^- levels in the compost reactor ranged from <4 µg/L to 140 µg/L. Effluent ClO_4^- levels in the cottonseed meal reactor ranged from <0.02 µg/L to 310 µg/L and effluent ClO_4^- levels in the canola-oil reactor ranged from <4 µg/L to 480 µg/L. The granular activated carbon reactor was shown to have removed only 90% of ClO_4^- during the start of the test and its performance declined over the course of the study as breakthrough occurred.

In order to complete the pilot-scale evaluation, three portions of the existing cutoff and collection trench were modified. The first area consisted of compost at 15% to 20% by volume mixed with drainage aggregate. The second area consisted of granular activated carbon (at 2 lb per foot of trench) placed on top of bedding gravel. The third area consisted of cottonseed placed within the bedding gravel at a rate of approximately 20 lb per ft of trench. Cottonseed meal was then placed on top of the cottonseed at a rate of 2 lb per foot of trench. The system was designed to operate in either a passive mode with the natural groundwater gradient or an active mode with pumping from several lift stations. The active mode could be used as necessary to control the water level in the trench and to promote recirculation of groundwater to increase contact with the trench media.

ClO_4^- levels in the trench prior to startup ranged from 16,000 to 27,000 µg/L. Two weeks after media installation, groundwater samples from the trench indicated that anaerobic conditions had been achieved (e.g., ORP <50 mV) and that ClO_4^- had been reduced to non-detect levels (<20 to <100 µg/L). Nitrate was also reduced from 15,000 µg/L to non-detect (<50 mg/L). After three months in place, ClO_4^- concentrations in the modified collection trenches were still at non-detect levels. In addition, TCE and 1,1-TCA levels were reduced to below detection limits, with the concentration of daughter products (e.g., 1,2-DCE or 1,1-DCA) increasing in groundwater. Although effective reduction of ClO_4^-, nitrate, TCE, and 1,1-TCA was demonstrated within the trench, downgradient monitoring wells had not yet shown an effect after three months. This was attributed to the low groundwater velocities at the site and the fact that more time would be needed for treated groundwater to reach the downgradient monitoring wells (Perlmutter, 2001).

Recirculation Systems and Biobarrier Case Studies at Aerojet in California

Three successful field-scale demonstrations of in situ ClO_4^- biodegradation have been completed at the Aerojet Facility in Rancho Cordova, California. As part of the Superfund process, several technologies have been tested at this site including several different in situ bioremediation amendments and delivery configurations. The key results from a pilot-scale closed loop recirculation system (5 gpm), a pilot-scale active biobarrier system (20 gpm), and another larger field-scale recirculation system (1,000 gpm) are discussed in following paragraphs.

The ClO_4^- plume at Aerojet originates from a former disposal/burn area. The ClO_4^- plume is approximately 5,000 ft long and 3,000 ft wide in an alluvial aquifer with interbedded silts, sands, and gravel. ClO_4^- levels in the aquifer range from 12 to 15 mg/L. Nitrate levels range from 5 to 24 mg/L.

Sulfate levels are at approximately 10 mg/L. The groundwater is aerobic and oxidizing with dissolved oxygen at 2 to 5 mg/L and ORP ranging from 143 to 263 mV. Chlorinated solvents are also present in the groundwater with TCE levels of approximately 2 mg/L. The impacted aquifer is at a depth of about 100 ft bgs and the groundwater treated during these pilot tests was at depths ranging from 85 to 175 ft bgs. The horizontal hydraulic gradient at the site has been estimated at approximately 30 ft/day and the vertical gradient at 3 ft/day. The groundwater plume is currently captured at the site boundary and treated for chlorinated VOCs and ClO_4^- (using ex situ biological treatment with FBRs) prior to reinjection (Geosyntec, 2002).

The fist demonstration was a closed loop recirculation system with 65 ft between a paired extraction and injection well. The flowrate of the system was 5 gpm and the total residence time within the treatment zone was approximately 21 days. During the pilot test, acetate was injected in 4 one-hour pulses per day at an average concentration of approximately 50 mg/L. Two monitoring wells were used to measure system performance. The first well was 15 ft away or a travel time of 2.5 days from the injection well according to tracer tests. The second well was 35 ft away or a travel time of 7 days from the injection well. Within 40 days of startup, ClO_4^- levels were reduced from 12 mg/L to <4 µg/L at the first monitoring well. After about 50 days, the ClO_4^- levels at the second well dropped from 15 mg/L to <4 µg/L. The half-life for ClO_4^- was estimated to be between 0.2 and 1.8 days. In addition, the groundwater went from aerobic and oxidizing to mildly reducing or slightly oxidizing as a result of electron donor delivery. During the test, the dissolved oxygen levels dropped to less than 1 mg/L and the ORP ranged from –25.6 to 19.7 mV (McMaster and Cox, 2001).

The second pilot-scale system consisted of an active biobarrier configuration with two upgradient extraction wells (10 gpm each) and one downgradient injection well (20 gpm). The system was designed to extract groundwater from the two extraction wells, amend the groundwater with electron donor, and then reinject the treated water into a downgradient injection well. Instead of setting up a recirculation zone with multiple passes of groundwater through a treatment zone, an active biobarrier is created that will reduce ClO_4^- in downgradient groundwater after a single pass.

The active biobarrier system was installed at the site of the first demonstration project. The 8-inch injection well from the first project was retained and two new 6-inch extraction wells were installed at 200 ft on either side of the original injection well. Groundwater modeling results indicated that pumping the extraction wells at 10 gpm each would provide capture of the core of the ClO_4^- plume in the pilot study area and would set up a hydraulic barrier with a total width of 600 ft across the site. The extracted groundwater was then combined, amended with ethanol, and recharged at 20 gpm into the central injection well. Equipment for the system included submersible pumps, on-line monitoring devices for pH, ORP, ClO_4^-, and groundwater flowrate, low-level pump switches for the extraction wells, and a high-level pump switch for the injection well. A metering pump was used to add ethanol to the extracted groundwater. Ethanol was selected because it was found to be the most cost-effective donor for large-scale use and it did not contribute metals, cations, or anions to the groundwater (e.g., like molasses or lactate). During operation, ethanol was added to the subsurface in a pulsed mode with a single one-hour pulse per day at an average ethanol concentration of 50 mg/L. A programmable logic controller (PLC) was used to control and automate the extraction, injection, and amendment delivery. In addition, five 2-inch monitoring wells were installed to assess the performance of the system as listed in Table F-3.

Table F-3. Summary of Key Results from Active Biobarrier Demonstration

Monitoring Well	Distance	Travel Time	Initial [Final] ClO$_4^-$ Levels	Non-detect Date	DO Range[a]	ORP Range[a]
Well 3601	15 ft down-gradient	NA	7.8 mg/L [<4 µg/L]	9 days	0.4 to 4.1 mg/L	-119 to 183 mV
Well 3600	35 ft down-gradient	5 days	7.8 mg/L [<4 µg/L]	9 days	0.7 to 1.5 mg/L	-113 to 213 mV
Well 100	65 ft down-gradient	10 days	6.3 mg/L [<4µg/L]	29 days	1.9 to 4.5 mg/L	-130 to 25 mV
Well 3618	100 ft down-gradient	38 days	3.9 mg/L [0.15 mg/L]	Not ND after 72 days	0.8 to 2.7 mg/L	10 to 185 mV
Well 3617	50 ft cross-gradient	5 days	8.0 mg/L [<4 µg/L]	20 days	0.5 to 4.1 mg/L	-102 to 214 mV

Note: DO and ORP range from Day One of test forward.

Table F-3 also summarizes some of the key results from the study. Prior to testing at the site, the aquifer was aerobic and oxidizing with dissolved oxygen at 2 to 5 mg/L and ORP ranging from 143 to 263 mV. The pH ranged from 6.88 to 7.20. Within 6 to 9 days of system startup, the ORP declined and stabilized over the duration of the test at -50 to -100 mV up to 65 ft away from the injection well. Dissolved oxygen decreased to levels below 1 mg/L within 35 ft of injection. ClO$_4^-$ was rapidly reduced during the test as shown in Table F-3. ClO$_4^-$ was reduced to non-detect (<4 µg/L) within 29 days at a distance of up to 65 ft downgradient from the injection well. The ClO$_4^-$ half-life was estimated at 0.5 to 1.2 days and was comparable to the results from the first demonstration at 0.2 to 1.8 days (McMaster and Cox, 2001). Several other monitoring parameters were tracked during the pilot test including chloride, nitrate, TCE, and ethanol concentrations in the groundwater. Chloride levels in groundwater were shown to increase slightly from 35 mg/L to 37 to 39 mg/L as ClO$_4^-$ was degraded. Nitrate was reduced from 23 mg/L to less than <0.5 mg/L within 6 to 9 days at distances up to 65 ft downgradient of the injection well. The half-life for nitrate was estimated to be 0.6 to 0.7 days. In addition, rapid and complete dechlorination of TCE to ethene was demonstrated within 35 to 65 ft of the injection well. The calculated half-life for TCE to ethene was 11 days. The ethanol injected into the subsurface was completely depleted within 100 ft of the injection well. The only adverse impact to groundwater noted during the test was the mobilization of low levels of manganese at 1 mg/L. Some operational difficulties were also experienced with the injection well. During the first month of operation the water levels in the injection well rose over time (~20 ft). A chlorine dioxide system was installed after one month to control biofouling in the injection well. Chlorine dioxide was periodically pulsed into the system at concentrations of 29 to 88 ppm over 0.7 to 2.5 hour periods. Approximately nine chlorine dioxide injections were performed over the four months of operation. Despite treatment, injection flowrates were impacted by biofouling and had to be reduced from 20 gpm to 8 to 14 gpm towards the end of the test. However, the water levels were relatively stable in the extraction wells and did not show any clogging from mobilized aquifer fines or other factors (Geosyntec, 2002).

The third demonstration project at Aerojet relied upon modification of a pre-existing pump and treat system. The extracted groundwater was treated for chlorinated VOCs (~ 2 mg/L influent) prior to reinjection into the aquifer. Instead of an ex situ treatment system for ClO$_4^-$, ethanol was added as an electron donor and the groundwater was reinjected in the subsurface at depths of 125 to 175 ft bgs. The reinjected groundwater contained ClO$_4^-$ at levels up to 250 µg/L. It was also saturated with dissolved oxygen at 8 mg/L and had nitrate levels of approximately 9 mg/L. Five reinjection wells are used to recharge the aquifer at 1,000 gpm or approximately 200 gpm per well. After approximately one month of

operation, ClO_4^- levels were non-detect at a monitoring well that was 75 ft away from injection point. During this demonstration, biofouling control was also found to be crucial to effective system operation. One injection well without biofouling control experienced an increase in water levels of about 20 ft, while another well with biofouling control showed an increase in water levels of less than 5 ft (Cox, 2002).

Conclusions

Several factors are important in determining if in situ bioremediation is feasible at a given site including: the depth to groundwater, the aerial extent of the groundwater plume, aquifer geochemistry, the presence of other chemical constituents, the need for hydraulic control, economics, regulations, and other issues (Hatzinger, 2000). ITRC notes that one of the most important criteria in deciding if in situ bioremediation is appropriate is the hydraulic conductivity of the aquifer. In situ bioremediation is best suited to sites with hydraulic conductivities ranging from 10^{-5} cm/s to 1 cm/s. Amendment delivery may be difficult at sites with very low hydraulic conductivities (e.g., less than 10^{-4} cm/s). In addition, sites with very high hydraulic conductivities (e.g., $>10^{-1}$ cm/s) may require high pumping and injection rates to achieve hydraulic containment and/or to provide effective amendment delivery (ITRC, 1998).

The aquifers at JPL are sandy with some intermittent silty layers. Estimated hydraulic conductivities range from 2.1 to 9.5 ft/day or 7.4 x 10^{-4} to 3.4 x 10^{-3} cm/s. In situ bioremediation seems to have potential at JPL given the fact that perchlorate-reducing microbes are present in the aquifer and that relatively rapid biodegradation rates have been demonstrated in site-specific microcosm studies with the addition of a variety of electron donors. However, due to the depth of groundwater contamination at JPL, the primary challenge will be to find a cost effective means to deliver the electron donor. The most elevated ClO_4^- concentrations at JPL are present in the first hydrostratigraphic layer (defined as 18 to 280 ft bgs). The primary advantages and limitations associated with the use of in situ bioremediation are as follows:

Advantages

- In situ bioremediation can be used to treat ClO_4^- hot spots that serve as a long-term source to groundwater.

- In situ bioremediation can be used to set up a biobarrier to prevent off-site chemical migration.

- In situ bioremediation destroys ClO_4^- and does not just concentrate it into a brine as with physical methods.

- At some sites, in situ bioremediation can be configured so that no aboveground treatment and/or disposal of groundwater is needed.

- At sites with shallow groundwater and/or a small aerial extent, semi passive or passive delivery methods may involve less capital and operation and maintenance costs compared to ex situ treatment options.

- Chlorinated VOCs (e.g., PCE and TCE) may also be degraded with electron donor delivery to the subsurface.

Limitations

- The number of field-scale applications conducted to date is limited.

- In situ bioremediation is best suited to sites with well-defined source areas and shallow or narrow zones of contamination.

- Biofouling can cause significant operation and maintenance issues over the long-term.

- Inefficient donor delivery can lead to little or no in situ biodegradation of ClO_4^-.

- Low pH, high salinity, and the presence of other compounds (e.g., nitrate) can influence the rate and extent of ClO_4^- degradation.

- In situ bioremediation can adversely impact groundwater quality (e.g., metals mobilization, sulfide release, methane production), so care should be taken to minimize these effects in drinking water aquifers.

- Regulatory approval must be received for amendment injection and/or groundwater reinjection.

Potential physical treatment methods reported in the literature for ClO_4^- include ion exchange, various membrane processes, and granular activated carbon adsorption.

Ion Exchange

Ion exchange involves removing ions from solution through sorption onto a resin. These resins contain positively charged adsorption sites onto which exchangeable anions (typically chloride) are bound. As contaminated groundwater is passed through the resin, ClO_4^- and other anions are sorbed to the resin. The chloride is then released into the effluent stream. The resin eventually becomes saturated with ClO_4^- and other anions such as nitrate and sulfate and must be regenerated. In the regeneration step, a sodium chloride brine is passed through the spent resin and displaces the adsorbed ClO_4^- and other anions from the resin. The ClO_4^- and other anions transferred into the brine solution must then be treated before disposal. A single resin can be regenerated several times before it is spent. Ion exchange concentrates, but does not destroy ClO_4^-, which means that several challenges exist related to brine generation, treatment, and disposal. The waste brine from ion exchange is often very difficult to treat because it can contain very high ClO_4^- concentrations, up to 6 wt% salts, and caustic components. If inexpensive ion exchange resins are used, it is sometimes more cost-effective to incinerate them rather than to pay to treat the regenerant brine (Gingras and Batista, 2002). If regeneration is needed, several authors have proposed ClO_4^- removal through biological treatment or catalytic reduction of the brine (e.g., Gingras and Batista, 2002; Aske, 2002).

Several types of ion exchange resins exist, including weak acid cation (WAC), weak base anion (WBA), strong acid cation (SAC), and strong base anion (SBA) resins and the proper resin is selected based on the type of ion targeted for removal. The goal of resin selection for ClO_4^- removal is to identify a resin that is both highly selective towards ClO_4^-, but is still easily regenerated. These are somewhat competing objectives because the more selective the resin, the more difficult it will be to remove the ClO_4^- during regeneration. Both acrylic and styrenic SBA resins have been demonstrated to remove ClO_4^- to low levels. However, only polyacrylic WBA resins have been demonstrated to achieve satisfactory ClO_4^- removal. Both SBA resins (e.g., Amberlite IRA400 Type I, Dowex MSA-1 Type I, Dowex 550A Type I and Ionac A-641 Type I) and WBA resins (IonacAFP-329 and IonacA-305B) were tested at JPL during preliminary groundwater treatability tests. All of the resins tested were shown to remove ClO_4^- to non-detect (<4 µg/L) levels (Foster Wheeler, 2000). SBA resins have a higher selectivity for ClO_4^- than WBA resins, but are therefore more difficult to regenerate. The ammonium hydroxide solutions used for WBA resin regeneration may also be more suitable for regenerant biological treatment compared to the very high salinity solutions used in SBA resin regeneration. In addition to SBA and WBA resins, a new class of anion exchange resins called bifunctional resins has been developed that have a very high selectivity for ClO_4^-. These resins have been demonstrated to be five times more efficient at removing ClO_4^- compared to conventional ion exchange resins. However, a special procedure using a $FeCl_3$-HCl solution must be used to achieve effective regeneration and bifunctional resins are more expensive than commercially available resins (Gingras and Batista, 2002). Table F-4 contains a summary of the key results from selected ion exchange studies for ClO_4^- removal and a discussion of case studies is provided below.

Characteristics of various commercially available resins

Researchers at the American Water Works Association Research Foundation (AWWARF) investigated various resins which were commercially available for their capabilities for removing Perchlorate and the effects of temperature and other natural surroundings to their functioning (Table 1, Tripp et. al., 2003).

The study demonstrated that the ion-exchange process with partial regeneration and simple waste brine disposal was cost effective for the treatment of perchlorate-contaminated water when compared to the cost of wholesale purchasing. It also demonstrated that brine treatment through a physical-chemical perchlorate and nitrate destruction system had a significant impact on the cost of the treatment, even though the salt usage costs associated with the brine treatment and reuse options were reduced by approximately 75%. This was because the overall Operation and maintenance cost went up because of the high costs associated with the need for Nanofiltration process for sulfate removal. This made the researchers assess the needs for biological treatment of the brine for reuse options, which proved to be more economical than the physical/chemical processes (Tripp et. al., 2003).

Researchers also encountered a decrease in perchlorate selectivity with the rise in temperature which led them to make a conclusion that during regeneration the temperature of the resin can be raised which can make the resin less selective and so most of the perchlorate can be removed from the resin by the brine spiked with sodium chloride. Therefore, regeneration at higher temperatures was found to be more efficient, and less chloride was required to remove the perchlorate (Tripp et. al., 2003).

One of the major outcomes of the study was that a highly perchlorate selective resin (Ionac SR-7) should be used for the best results. Polysterene resins can also be used but the problem is the production of N-nitrosodimethylamine (NDMA) within the resin. The state of California currently has a provisional action limit of 20 ng/L for NDMA in drinking water. Therefore, even small amounts produced due to the ion-exchange resins could be a potential problem (Tripp et. al., 2003).

Highly selective anion exchange resins offer considerable advantages over conventional (unselective) resins in the treatment of perchlorate contaminated groundwater. Oak Ridge national Laboratory has developed anion-exchange resins that have a bias for the sorption of large poorly hydrated anions such as perchlorate from contaminated groundwater. Laboratory results at the ORNL indicated that the bifunctional resins, D-3696 (made by Purolite International) and RO-02-119 (prepared at the University of Tennessee-Knoxville), were highly selective toward perchlorate and performed five times better that the best commercial nitrate resin (Purolite A-520 E) and more than an order of magnitude better than some non-selective commercial resins (e.g. Amberlite IRA-900). The bifunctional reins were particularly effective in removing trace quantities of perchlorate in groundwater to below the detection limits (Gu et. al., 1999).

Table F-4: Characteristics of the strong base anion (SBA) resins investigated by various researchers for the AWWARF (Tripp et. Al. ,2003)

Resin Number	Resin Name	Matrix	Functionality	Perchlorate selectivity	Temperature Effect	Manufacturer
1	Duolite A-101D	STY-DVB [a]	Q-1 [c]	High	Increase in Temperature decreased perchlorate selectivity	Rhom and Haas, Philadelphia, Pennsylvania
2	Duolite ES-171	STY-DVB	Q-1	High	Increase in Temperature decreased perchlorate selectivity	Rhom and Haas, Philadelphia, Pennsylvania
3	Duolite ES-181	STY-DVB	Q-1	High	Increase in Temperature decreased perchlorate selectivity	Rhom and Haas, Philadelphia, Pennsylvania
4	Ionac ASB-1	STY-DVB	Q-2 [d]	High	Increase in Temperature decreased perchlorate selectivity	Sybron Chemicals, Pittsburgh, Pennsylvania
5	Ionac ASB-2	STY-DVB	Q-2	High	Increase in Temperature decreased perchlorate selectivity	Sybron Chemicals, Pittsburgh, Pennsylvania
6	Ionac SR-7	STY-DVB	TPA [e]	Higher than other Polysterene resins, highest among all the resins	Increase in Temperature decreased perchlorate selectivity	Sybron Chemicals, Pittsburgh, Pennsylvania
7	Lewatit OC-1950	STY-DVB	Q-1	High	Increase in Temperature decreased perchlorate selectivity	Leverkusen, Germany
8	Amberlite IRA-400	STY-DVB	Q-1	High	Increase in Temperature decreased perchlorate selectivity	Rhom and Haas, Philadelphia, Pennsylvania
9	Amberlite IRA-402	STY-DVB	Q-1	High	Increase in Temperature decreased perchlorate selectivity	Rhom and Haas, Philadelphia, Pennsylvania

Table F-4: **Characteristics of the strong base anion (SBA) resins investigated by various researchers for the AWWARF (Tripp et. al. ,2003) (Continued)**

Resin Number	Resin Name	Matrix	Functionality	Perchlorate selectivity	Temperature Effect	Manufacturer
10	Amberlite IRA-404	STY-DVB	Q-1	High	Increase in Temperature decreased perchlorate selectivity	Rhom and Haas, Philadelphia, Pennsylvania
11	Amberlite IRA-458	Acrylic	Q-1	Low	Not much change	Rhom and Haas, Philadelphia, Pennsylvania
12	Amberlite IRA-900	STY-DVB	Q-1	High	Increase in Temperature decreased perchlorate selectivity	Rhom and Haas, Philadelphia, Pennsylvania
13	Amberlite IRA-958	Acrylic	Q-1	Low	Not much change	Rhom and Haas, Philadelphia, Pennsylvania
14	Amberlite IRA-996	STY-DVB	TEA [f]	High	Increase in Temperature decreased perchlorate selectivity	Rhom and Haas, Philadelphia, Pennsylvania
15	Reillex HPQ	PYR-DVB [b]	Methylpyridine	High	Increase in Temperature decreased perchlorate selectivity	Reily Enterprises, Indianapolis, Indiana
16	Reillex B-1	PYR-DVB	Benzylpyridine	Higher than the other polyvinyl pyridine resins	Increase in Temperature decreased perchlorate selectivity	Reily Enterprises, Indianapolis, Indiana
17	Reillex DP-1	PYR-DVB	Dipyridine	High	Increase in Temperature decreased perchlorate selectivity	Reily Enterprises, Indianapolis, Indiana

(a) STY-DVB: Polysterene-divinylbenzene polymer

(b) PYR-DVB:Polyvinylpyridine-divinylbenzene polymer

(c) Q-1:Quaternary amine, type I

(d) Q-2: Quaternary amine, type II

(e) TPA:Tripropyl amine

(f) TEA:Triethyl amine

Case Study: **Comparison of the perchlorate selectivity of the Bifunctional resins with the commercially available resins**

Highly selective Bifunctional anion exchange resins offer considerable advantages over conventional (unselective) resins in the treatment of perchlorate (ClO_4^-) contaminated groundwater. B. Gu et. al. at the Oak Ridge National Laboratory (ORNL) investigated anion-exchange resins which were all based on a poly (vinylbenzyl chloride) backbone, cross-linked with divinylbenzene (DVB), which contains chloromethyl reaction sites that were functionalized by reaction with various trialkylamine groups to create quaternary ammonium strong-base exchange sites. A systematic study was performed to evaluate the effects of different trialkyl functional groups (or their combinations) in the resin, as well as the percentages of DVB cross-linking, on the resin's selectivity for sorption of ClO_4^-. All synthetic resins were prepared in the laboratory of Professor Spiro Alexandratos of the Department of Chemistry, University of Tennessee, Knoxville. A commercial scale-up version of one of Prof. Alexandratos' resins was prepared to specifications provided by the ORNL investigators by Purolite International (Purolite [®] D-3696). Three commercially-available anion-exchange resins were also selected for investigation, and the performance of these resins formed a benchmark that was the basis for comparison with the new resins. These commercial resins were Purolite [®]A-520E (a resin with triethylamine exchange sites), Sybron Ionac SR-6 (a resin with tributylamine exchange sites), and Amberlite [®]IRA-900 (a resin with trimethylamine exchange sites). (Gu et. al., 1999)

Perchlorate sorption on synthetic resins was determined by bringing 0.1g resin (dry weight equivalent) of ion exchange resin in contact with a solution containing a varying amount of ClO_4^- (100 ml of test solution). The test solution was a stimulant of a typical contaminated groundwater found in Redlands, California and also a sample of groundwater contaminated with ClO_4^- obtained from CrimSouth well, Redlands, California. (Gu et. al., 1999)

Process Description

Laboratory column flow-through experiments were performed using small glass chromatographic columns (10 X 40 mm). Resins were wet packed into the columns and the solution was fed into the columns at a constant speed of 30 mL/min. As seen in Figure F-1, for the field trial three pairs of ion-exchange columns (25 X 115 mm glass columns) with different resins were used. The contaminated groundwater was pumped through the column set at a flow rate of ~200 mL/min per column set. The inlet pressure ranged from ~20 to 30 psi and varied slightly in each individual column. The flow rate was kept relatively constant (between 150 and 210 mL/min) by adjusting the inlet pressure (or flow rate) periodically. (Gu et. al., 1999)

The distribution coefficient for sorption of ClO_4^- to the resins, $K`_d$ (in mg/L) was calculated as the ratio of ClO_4^- sorbed (expressed as mg per gram of resin) to the concentration of ClO_4^- remaining in solution (mg/mL), that is,

$$K`_d = \frac{\text{perchlorate sorbed on the resin (mg/g)}}{\text{perchlorate in solution (mg/mL)}} = \frac{(Co - C)/m}{C}$$

Where Co and C are the initial and final concentrations (mg/mL) of ClO_4^- in solution, and m is the mass of resin per unit volume of solution (expressed as g/mL). The apparent distribution coefficient was measured as a function of time, and equilibrium was assumed to be reached when the apparent $K`_d$ value no longer changed. (Gu et. al., 1999)

Results and Discussion

Results from the column studies indicated that the ORNL-developed bifunctional resins were much more selective toward ClO_4^- (K'_d values were 2 - 5 times higher) than the two commercial resins (Purolite [®]A-520E and Sybron Ionac [®] SR-6). At an initial concentration of ~1 mg/L ClO_4^- the bifunctional resins removed the ClO_4^- in solution to below the detection limit (~0.003 mg/L) within 1 h. The synthetic monofunctional resin VP-02-152 (tripropylamine resin) reduced the perchlorate to below detection limits within 24 h. On the other hand, the commercial resins Purolite[®]A-520E and Sybron Ionac[®]SR-6 took ~1 week to remove ClO_4^- below the detection limit. The laboratory scale study thus led to the conclusion that the bifunctional resins are particularly effective in removing trace quantities of ClO_4^- in aqueous solution as it is commonly encountered under natural groundwater conditions. (Gu et. al., 1999)
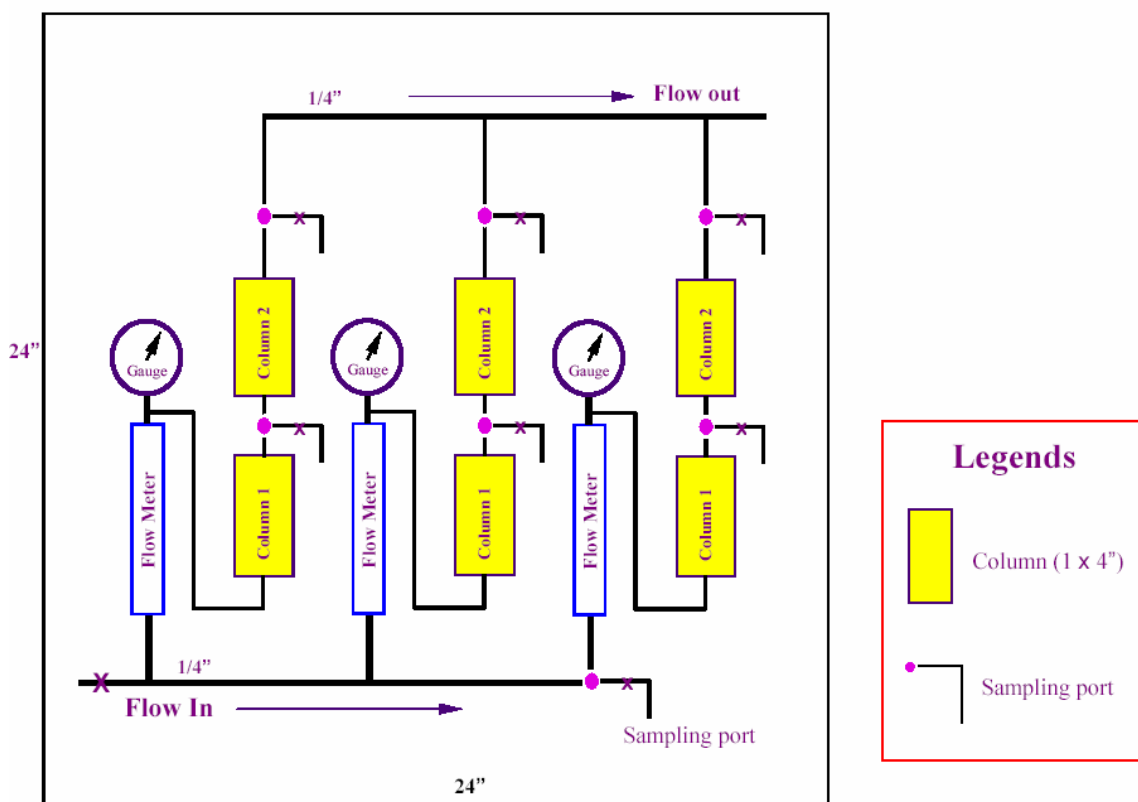
Figure F-1: Design of the field experiment for the flow-through column testing (Gu et. al., 1999)

Results from the small-scale field test indicated that the bifunctional synthetic resin (D-3696) prepared by Purolite for ORNL performed ~5 times better than the best commercial nitrate-selective resin (Purolite [®] A-520E). Breakthrough of ClO_4^- on the Purolite [®]A-520E lead column occurred after ~8,500 bed volumes of groundwater had passed through the column. On the other hand, ClO_4^- breakthrough occurred at ~40,000 bed volumes in the D-3696 resin column. In the second column ~3% breakthrough of ClO_4^- occurred at ~22,000 bed volumes in the Purolite [®]A-520E column but this breakthrough level required ~104,000 bed volumes in the D-3696 column. At a 10% breakthrough (presumably the remediation target), the bifunctional D-3696 resin was able to treat up to ~112,000 bed volumes of groundwater containing ~50µg/L ClO_4^- (as seen in Table F-5) and running at ~2 bed volumes per minute (or at a residence contact time of <20 s).The best commercial resin (Purolite [®] A-520E, the nitrate selective resin)

treated up to ~24,000 bed volumes of the groundwater under the same experimental conditions. These observations suggested that the bifunctional resin, D-3696, can also adsorb more ClO_4^- than Purolite $^®$ A-520E after the breakthrough occurs. In other words, the bifunctional resin columns may be configured with a relatively long pass length to enhance its treatment efficiency and longevity. (Gu et. al., 1999)

Table F-5: Major contaminants and chemical properties of groundwater at the experimental field site. (Gu et. al., 1999)

Property	Site groundwater
Cl^- (mg/L)	7.0
NO_3^- (mg/L)	61.2
$SO_4^=$ (mg/L)	14.9
Ca^{2+} (mg/L)[1]	21.7
Alkalinity (mg/L)[1]	98.6
ClO_4^- (mg/L)	0.05
N–NDMA (mg/L)[1]	0.15
Trichloroethylene (mg/L)[1]	0.3
pH	6.9

The groundwater was pumped directly through the resin columns without any pretreatment. This resulted in retention of some dissolved organic matter (DOM) present in the natural groundwater. These organic materials in groundwater are generally negatively charged, so that they can also be strongly adsorbed by the anion exchange resins and may compete with the adsorption of ClO_4^- on the resin beads. The Purolite $^®$ A-520E appeared to have retained the least amount of DOM by visual comparison of the columns. However, the retention of the DOM did not appear to significantly reduce the performance of the Purolite bifunctional resin to remove ClO_4^-, which may be again attributed to the high selectivity of the bifunctional resins to poorly hydrated oxyanions such as ClO4-. These observations suggest that additional cost-savings could be gained by using highly selective synthetic resins in groundwater ClO4-treatment. Unlike the conventional groundwater treatment which normally requires a pretreatment stage to remove or filter DOM and other competing anions (such as SO_4^{2-}) that would otherwise reduce or interfere with the retention and removal of ClO_4^-, the use of highly selective bifunctional resins requires no pretreatment. (Gu et. al., 1999)

Bifunctional Anion Exchange Study at Edwards Air Force Base, CA

A pilot-scale test was conducted at Edwards Air Force Base in California to investigate the use of bifunctional anion exchange resins for the treatment of perchlorate-contaminated groundwater. The primary advantages associated with bifunctional resins include the fact that ClO_4^- is preferentially removed over other common anions in groundwater and that the higher adsorption means the system can be operated with a higher flowrate and/or a smaller volume than conventional ion exchange systems. For the initial phase of the pilot test, both a bifunctional resin (Purolite D-3696) and a monofunctional resin (Purolite A-520E) were run in parallel. Each ion exchange column was 2 inches in diameter and 12 inches in depth and received a flow of groundwater at 500 to 700 mL/min. This flowrate corresponds to about one bed volume per minute. Finally, a third ion exchange column was used as a polishing step to capture any residual ClO_4^- prior to discharge of the treated groundwater. Influent ClO_4^- levels ranged from 400 to 500 µg/L (Gu et al., 2002).

It was demonstrated that initial breakthrough of the monofunctional resin occurred after 14,000 bed volumes, whereas full breakthrough occurred at 35,000 bed volumes. By comparison, initial breakthrough occurred at 20,000 bed volumes for the bifunctional resin and full breakthrough at 56,000 bed volumes. It was estimated that more than 5,400 mg of ClO_4^- was retained in the monofunctional resin, whereas more than 10,700 mg was retained in the bifunctional resin. However, it was discovered that iron oxyhydroxide precipitation and biomass growth had impacted both ion exchange columns and caused clogging, so a second test was conducted with fresh bifunctional resin. A filter (0.5-µm pore size) was added to the inlet of the system to prevent clogging of the new bifunctional resin column. During the second test, the flowrate through the bifunctional resin column was set at 700 mL/min. The performance of the bifunctional resin was significantly improved during the second test. Initial breakthrough did not occur until about 40,000 bed volumes and more than 10,000 mg of ClO_4^- was retained in the resin. The researchers were also able to demonstrate that the spent bifunctional resin bed could be successfully regenerated using the $FeCl_3$-HCl technique recently developed at Oak Ridge National Laboratory. Almost 100% of the sorbed ClO_4^- was recovered with only two bed volumes of regenerant solution. The maximum concentration of ClO_4^- in the regenerant brine was 60,000 mg/L. The regeneration technique involves the use of the tetrachloroferrate anion ($FeCl_4^-$), which has a stronger affinity for the resin than ClO_4^-. However, this anion can later be decomposed to Fe^{3+}, $FeCl^{2+}$, and $FeCl_2$ species that will readily desorb from the resin. Next, the Fe(III) species are washed out of the resin bed using a dilute HCl solution followed by a water rinse. The rinsing step requires about 20 to 30 bed volumes to remove the ferric ions to a low or non-detect level in the effluent (Gu et al., 2002).

Table F-6. Selected Ion Exchange Treatment Case Study Results

Author	Scale	Resin Type	Resin Brand	Column Size	EBCT	Total Flow-rate	Regenerant Type	Regenerant Volume	Initial [Final] ClO_4^- Levels	ClO_4^- Breakthrough	Initial [Final] Nitrate Levels
Najm et al., 1999	L	SBA Polystyrene	Rohm & Hoss IRA400	13 mL Resin Volume	1.5 min	13 mL/min	NaCl (>60 lb/ft^3)	4 Bed Volumes	200 µg/L [<4 µg/L]	7,500 Bed Volumes	9 mg/L [NA]
Najm et al., 1999	L	SBA Polystyrene	Sybron ASB-2	13 mL Resin Volume	1.5 min	13 mL/min	NaCl (30 to 45 lb/ft^3)	4 Bed Volumes	200 µg/L [<4 µg/L]	6,000 Bed Volumes	9 mg/L [NA]
Najm et al., 1999	L	SBA Polyacrylic	Rohm & Hoss IRA458	13 mL Resin Volume	1.5 min	13 mL/min	NaCl (30 to 45 lb/ft^3)	4 Bed Volumes	200 µg/L [<4 µg/L]	450 Bed Volumes	9 mg/L [NA]
Najm et al., 1999	P	SBA Polyacrylic	Purolite A850	0.062 ft^3	1.5 min	0.3 gpm	NaCl (30 to 45 lb/ft^3)	16 Bed Volumes	90 to 140 µg/L [<4 µg/L]	725 Bed Volumes	6.6 mg/L [NA]
Najm et al., 1999	P	SBA Polystyrene	Sybron ASB-2	0.062 ft^3	1.5 min	0.3 gpm	NaCl (30 to 45 lb/ft^3)	16 Bed Volumes	90 to 140 µg/L [<4 µg/L]	>750 Bed Volumes	6.6 mg/L [NA]
Najm et al., 1999	P	SBA Polyacrylic	Rohm & Hoss IRA458	0.062 ft^3	1.5 min	0.3 gpm	NaCl (30 to 45 lb/ft^3)	16 Bed Volumes	90 to 140 µg/L [<5 µg/L]	560 to 725 Bed Volumes	6.6 mg/L [NA]
Vankatesh et al., 2000	P	SBA Polyacrylic	ISEP^{+TM} process	30 small columns	16.6 min	4.28 gpm	NaCl (7 wt%)	0.75% Total Influent Flow	50 to 80 µg/L [<4 µg/L]	NA	22 to 28 mg/L [5 to 14 mg/L]
Vankatesh et al., 2000	P	SBA Polyacrylic	ISEP^{+TM} process	30 small columns	16.6 min per column	4.28 gpm	NaCl (7 wt%)	0.16% with PNDM	250 to 1,200 µg/L [<4 µg/L]	NA	15 to 20 mg/L [<2 mg/L]
Gu et al., 2002	P	SBA	Purolite 520E	2 in dia and 12 in length	1 min	500 to 700 mL/min	FeCl$_3$-HCl	6 Bed Volumes	400 to 500 µg/L [<4 µg/L]	14,000 Bed Volumes	0.7 mg/L [NA]
Gu et al., 2002	P	Bifunctional	Purolite D3696	2 in dia and 12 in length	1 min	500 to 700 mL/min	FeCl$_3$-HCl	2 Bed Volumes	400 to 500 µg/L [<4 µg/L]	20,000 to 40,000 Bed Volumes	0.7 mg/L [NA]
Burge and Halden, 1999	L/P	Nitrate Specific	Sybron SR-7	5.0 ft^3 Resin Volume	NA	0.62 /15 gpm	NaCl	2% Total Influent Flow	27 µg/L [<4 µg/L]	NA	100 mg/L [17 to 23 mg/L]

P = Pilot Scale.
L = Laboratory Scale.

Brine Treatment

The brine from regenerating an anion exchange resin bed contains high concentrations of perchlorate as well as high total dissolved solids (TDS). The brine stream may range from 1% to 5% of the volume of contaminated water treated, but is usually in the range of 1% to 2%. Approximately 10 pounds of salt is used to regenerate each cubic foot of resin. Technologies to treat the concentrated regeneration brine include:

Biological brine treatment: The Biological Brine Treatment process employs a closed reactor with multiple taps to introduce spent brine, draw-off treated brine, or simple water quality. The system is operated as a sequencing batch reactor and utilizes a marine sediment inoculum to biologically reduce both perchlorate and nitrate in a three percent brine solution. This system uses acetic acid as an electron donor for the reduction process (Case, 2003).

Physical/Chemical brine treatment: One of the Physical/Chemical brine treatment process has been developed by the Company Calgon Carbon and is called the Calgon ISEP system. This system employs a high-pressure and a high-temperature catalytic process to reduce the nitrate and perchlorate in the spent brine. After treatment, the brine is ready for reuse without additional treatment. The process uses a chemical reductant (ammonia) based on the measured concentrations of nitrate and perchlorate in the spent brine. Even ORNL has developed a method of degrading the perchlorate present in the brine completely to chloride and water using ferrous ion and/or non-toxic organic reducing agents and $FeCl_3$-HCl as a regenerant solution (US patent pending) (Case, 2003).

Applied Research Associates- Integrated thermal Treatment Process: Laboratory research demonstrated that perchlorate in regenerant brine could be thermally decomposed at elevated temperature and pressure with the addition of reducing agents and promoters. Concentration of the brine with reverse osmosis would be necessary to make the process cost-effective (US patent pending) (CA EPA, 2004).

Electrolytic brine treatment: A simple bipolar electrochemical cell was developed to electrolytically reduce the perchlorate and/or nitrate present in the spent ion-exchange brine. This process does not require the addition of an electron donor as with the biological process or a reductant as with the physical/chemical treatment process.

A study by the AWWARF has given the costs for some of the different brine treatment processes as:

- Brine Discharge (without perchlorate destruction) = $1.30/1,000 gallons ($430/acre-foot)

- Biological brine treatment with reuse = $1.15/1,000 gallons ($375/acre-foot)

- Physical/chemical brine treatment with reuse = $1.45/1,000 gallons ($465/acre-foot)

Biological Perchlorate Reduction for Ion Exchange Brine Treatment and Reuse

Various ion-exchange resins have been shown to remove perchlorate; disposal of the regenerate brine is economically taxing and without destruction of the perchlorate can lead to future litigation. To overcome this problem a research team comprising of MWH and the University of Houston has focused on evaluating methods of biologically treating spent ion-exchange brine.

Process Description

Designed, constructed and installed within MWH's Mobile Water Treatment Pilot Trailer, the pilot plant included two parallel ion-exchange columns (clear PVC) that could be operated independently in either co or counter-current exhaustion and regeneration. For this study the columns operated in a counter-current mode with up-flow exhaustion and down-flow regeneration. Screens were inserted at the top and bottom of each ion-exchange column to contain the resin in the column during the exhaustion and regeneration modes. The treated water was collected in a clear tank and the spent brine was either wasted or collected in a holding tank to be fed to the brine treatment system. (Gillogly et. al., 2004)

The biological brine treatment system was 208 L (55 gal) closed reactor operated as a sequencing batch reactor with a mixed culture of microorganisms using acetic acid as an electron donor. Ecology studies revealed that the pure cultures that could be developed on a solid media were all facultative, aerobic, nitrate-reducing organisms. None were identified as known human pathogens. One organism consistently seen in Gram stains, but resisted aerobic or anaerobic solid agar culture techniques was a Gram negative vibro and was suspected to be the salt tolerant perchlorate reducing organism. Once the nitrate and perchlorate are biodegraded, the mixture is settled, filtered and amended with chloride before its reuse as the regenerant solution. (Gillogly et. al., 2004)

Results and Discussion

Field-scale testing of ion-exchange with brine treatment utilized groundwater from an operational La Puente County Valley Water District well with 65 µg/L ClO_4^-. Testing results demonstrated that the biological brine treatment system was able to consistently reduce the perchlorate and nitrate concentrations in the spent brine to below treatment goals (<200 µg/L ClO_4^-) during 20 cycles of operation. The resin was regenerated with a 3 percent NaCl spent brine during the field testing. Within the 20 recycles there was an increasing trend in the concentrations of selected ions in the finished water quality was observed at the end of exhaustion. The particular problem encountered was the rising trend in the nitrate concentration clearly indicating the loss of sites for nitrate and perchlorate removal in the resin. The options suggested by the authors include 1) periodic wasting of the brine and the treatment to be continued with a fresh batch of brine 2) periodic wasting of small portion of the recycled brine and subsequently amend it with virgin sweet brine to limit the accumulation of other anions too 3) further processing of the brine like passing it through an Nanofiltration membrane. (Gillogly et. al., 2004)

Bench Scale Testing found that a brine solution with 6-8 % NaCl was good enough to completely remove the perchlorate in the solution. The optimal pH was 6-8 for a complete removal and the presence of other anions did not affect the perchlorate removal.(Gillogly et. al., 2004) It is already known that sulfate does not inhibit perchlorate removal by the nitrate or perchlorate selective resins. (Attaway and smith, 1993; Logan, 1998; Coates et. al. 1999)

An engineering cost model developed to determine the cost of brine treatment and reuse indicated that the cost of the ion-exchange process with biological brine treatment was

approximately around $1.15/1000 gallons and approximately $1.45/1000 gallons for physical/chemical brine treatment and reuse system. A conventional ion-exchange system with brine discharge (no perchlorate destruction) was estimated to cost $1.30/1000 gallons. (Gillogly et. al., 2003)

Bruce et. al. at the Pennsylvania State University have also demonstrated that the perchlorate-respiring microorganisms (PRM) can grow in solutions with high salinity, higher than 3% and upto 11%. The samples for perchlorate reduction were obtained from Great Salt Lake, Utah (GSL); salt marsh water, Delaware Bay estuary (DB); bottom sediments (SBS) and surface water (SBW) from a brackish coastal lagoon and a biofilm/sludge mixture from seawater filter system sludge (SBB) from the top of the large sand filter of the university seawater system. GSW and SBL samples demonstrated growth of PRM in highly saline environment also. This work demonstrated the potential of perchlorate contaminated brine solutions. (Logan et. al., 2001).

ISEP^{+TM} Case Studies

Calgon Carbon Corporation (Calgon) completed a 5-month pilot test at JPL to test the effectiveness of granular activated carbon (GAC) adsorption for VOC removal paired with Calgon's patented ion exchange process (ISEP^{+TM}) for ClO_4^- removal from groundwater. In addition, the ISEP^{+TM} process has been used at a groundwater remediation site in Henderson, Nevada.

The ISEP^{+TM} system consists primarily of an ion exchange unit, a perchlorate and nitrate catalytic destruction module (PNDM), a nanofiltration system for sulfate removal from the brine, and a reverse osmosis unit for rinse water treatment. A strong base polyacrylic Type I resin is typically used in this system. Calgon's ISEP^{+TM} system is configured to operate in a continuous sequence of ClO_4^- adsorption, regeneration, and rinsing. Continuous operation is made possible by a system of 25 to 30 ion exchange columns that are placed on a rotating carousel. Each column is packed with millions of small resin beads. First, the ClO_4^- present in the feed water is exchanged with chloride on the resin in the adsorption zone. The influent water is loaded in a downflow configuration from the top to the bottom of the column. The treated effluent from the adsorption zone typically contains <4 µg/L of ClO_4^-. Next, the resin containing the adsorbed ClO_4^- is rotated into the regeneration zone. A brine of sodium chloride is then pumped in an upflow configuration from the bottom to the top of the column. The regenerant flow is split equally and pumped into each column in the regeneration zone in parallel. The spent brine effluent will contain a high concentration of ClO_4^- and is sent to the PNDM for ClO_4^- and nitrate removal. The PNDM relies upon catalytic destruction and is described in more detail in the section on chemical treatment. After the PNDM unit, the brine effluent is passed through nanofiltration to remove sulfate. The treated brine is then routed to a regenerant storage tank where it can be reused in the regeneration process. The ISEP^{+TM} system reduces the volume of water used during the regeneration step both through the use of a counter current regeneration step and the recycling of treated brine from the PNDM back into the process. Finally, in the rinse zone, excess brine is removed from the column before it moves back into the adsorption zone. The rinse wash is treated by a reverse osmosis system. The permeate from the reverse osmosis system is reused again as rinse water and the rejectate is sent to the regenerant storage tank. The overall waste generation from the ISEP^{+TM} process is typically less than 0.2% by volume of the total influent flow (Vankatesh et al., 2000).

The objectives of the pilot-scale test at JPL were to demonstrate the successful removal of ClO_4^- from groundwater to levels less than 4 µg/L and to minimize the volume of waste produced. The pilot-scale system at JPL contained 30 ion exchange columns and was set for a residence time of 16.6 minutes for each column or 8.3 hours to complete one rotation of the system. During the pilot test, all chlorinated

VOCs were treated to non-detect during pretreatment with the GAC units. Influent ClO_4^- concentrations ranged from 250 to 1,200 μg/L and were treated to non-detect (<4 μg/L) in the effluent. Nitrate was treated from 15 to 20 mg/L in the influent to <2 mg/L in the effluent and sulfate was treated from 45 to 50 mg/L in the influent to <2 mg/L in the effluent. Two brief excursions did occur during testing and were caused by the inadvertent loss of regenerant flow to the system. The PNDM was demonstrated to reduce ClO_4^- concentrations in the regenerant brine from 60,000 μg/L to <125 μg/L. The results of the PNDM process are discussed in more detail in the section on chemical treatment with catalysts. During the testing, it was demonstrated that the overall waste generation from the ISEP^{+TM} system was only 0.16% by volume of the total influent flow (Calgon, 1999).

At a remediation site in Henderson, Nevada, the ISEP^{+TM} system was installed to treat perchlorate-contaminated seep water that was collected to prevent it from draining into Lake Mead. The system was started in 1999, but is reported to have been shutdown due to performance issues with the PNDM module. During full-scale operation, the system influent flowrates varied from 200 to 560 gpm and influent ClO_4^- concentrations range from 80 to 110 mg/L. Typical effluent ClO_4^- levels were reported to be non-detect at <2 mg/L as measured with an ion selective electrode (Wagner and Drewry, 2002).

ISEP^{TM} Case Study

A 2,500 gpm ISEP system was installed at the La Puente Valley County Water District in 2000 and is currently operational. It should be noted that the PNDM system was not used at this site because access to a local brine disposal line precluded the need for brine treatment. Use of the treated effluent for potable water distribution was begun in 2001. During pilot-scale testing at this site, it was demonstrated that ClO_4^- in the influent at 50 to 80 μg/L could be treated to non-detect (<4 μg/L) in the effluent. Nitrate was removed from 22 to 28 mg/L in the influent to 5 to 14 mg/L in the effluent. Sulfate was removed from 45 to 60 mg/L in the influent to less than 2 mg/L in the effluent. Even without the PNDM unit, the ISEP process only produced regenerant brine at 0.75% by volume of the total influent flow (Venkatesh et al., 2000). Currently, the brine (containing up to 7,000 mg/L of ClO_4^-) is discharged to the nearby industrial brine line. However, brine treatment with biological treatment is being considered and may be implemented within three years due to phasing out of the brine line (Williams, 2002).

Other Ion Exchange Systems

Several vendors offer package ion exchange systems with disposable resins. The West San Bernardino Water District (WSBWD) has one 2,000 gpm U.S. Filter Ion Exchange System and one 2000 gpm Calgon Ion Exchange System. These systems were installed in May of 2003. Each module of the U.S. Filter system consists of two vessels, skid mounted, with all piping, valves, and gauges assembled. Each resin vessel holds 600 ft^3 of resin that needs to be exchanged every 50 to 75 days. The resin is incinerated and the transport and disposal activities are contracted out to U.S. Filter. Some operational issues have been noted including sand accumulation in the resin vessels due to poor well development, bacteria build-up in the resin vessels, and nitrate leakage from the lead resin vessel. Perchlorate has been shown to be removed from 4 to 7 mg/L to non-detect and nitrate from 29 mg/L to non-detect.

Non Regenerable Resins

Dow Chemical Company manufactures DOWEX , anion exchange resin that can be applied as a once through processing tool. The value that a non-regenerated resin method provides is its ability to process large volumes of water while containing the perchlorate for disposal. Resin bound with perchlorate can be completely removed from a site and disposed of in a regulated landfill or sent for specialized incineration (Gisch, 2003).

Conclusions

Although ion exchange for ClO_4^- removal is very effective, the major drawback for its use is the need for treatment and/or disposal of the regenerant brine. For conventional ion exchange systems, the volume of brine generated is typically 2% to 5% of the total influent flowrate. Calgon's $ISEP^{+TM}$ process has demonstrated only 0.2% of brine production when ion exchange is coupled with catalytic destruction in a PNDM unit. $ISEP^{+TM}$ is substantially more cost-intensive than biological treatment and performance problems have been reported with the PNDM module at full-scale. Ion exchange was not retained for further consideration for the ETS at JPL because of the higher capital cost for ISEP and the higher operation and maintenance costs for disposable resins. The overall advantages and limitations associated with this technology are provided below:

Advantages

- Existing technology that has been tested at the pilot and full-scale.

- Dedicated commercial vendors and commercially available resins.

- Proven effectiveness at meeting <4 μg/L of ClO_4^- in effluent.

- Physical treatment technologies are more conventional for drinking water applications.

Limitations

- Operation and maintenance costs are typically higher than for biological treatment techniques.

- Not all resins are highly selective for ClO4- and other groundwater anions (e.g., nitrate, sulfate) may interfere with its removal.

- Brine treatment and disposal issues may limit cost-effectiveness.

Membrane Processes

Membrane processes include treatment techniques such as reverse osmosis (RO), nanofiltration (NF), and electrodialysis (ED). All of these processes rely upon a semiporous membrane that lets water pass through, but prevents dissolved salts from penetrating the membrane. RO and NF have been reported to achieve more than 80% removal of ClO_4^- from process streams. With all membrane processes, the ClO_4^- removed is not destroyed, but collected and concentrated in a waste brine. The treated effluent that is recovered is referred to as the permeate and the waste brine is referred to as the rejectate. The treated water or permeate must often be remineralized with sodium chloride, sodium bicarbonate, or other salts prior to distribution in drinking water systems to prevent corrosion or other adverse effects (Urbansky, 1999). According to the GWRTAC report, RO and NF are currently being tested for ClO_4^- removal at the laboratory scale by the American Water Works Association Research Foundation (AWWARF) and RO has been tested at the laboratory scale at an unspecified site in Panama City, Florida. Influent ClO_4^- levels for these studies ranged from 8 to 100,000 μg/L of ClO_4^- (GWRTAC, 2001). Reverse osmosis has also been tested at the laboratory scale at JPL as discussed below.

RO Case Study at Jet Propulsion Laboratory in California

U.S. Filter Corporation conducted a laboratory treatability study to assess the effectiveness of using RO to remove ClO_4^- from JPL groundwater. Both a thin film composite membrane and a cellulose acetate membrane were evaluated. Each bench-scale reactor was 2.5 inches in diameter and 40 inches in length with a 23 ft^2 RO module. The key results from the RO tests are summarized in Table F-7. The results from the thin film composite test were more promising than the cellulose acetate membrane test. In both tests, approximately 80% of the influent stream was recovered as permeate. However, with ClO_4^- influent levels of 800 μg/L, the thin film membrane achieved 12 to 16 μg/L in the permeate, whereas the acetate membrane contained ClO_4^- levels as high as 680 μg/L. The rejectate consisted of 20% of the influent stream and contained ClO_4^- at approximately 3,600 μg/L for the thin film membrane and 1,600 μg/L for the cellulose acetate membrane. The leakage of the cellulose acetate membrane was considered to be unacceptably high, so this membrane was eliminated from further consideration. The rejectate from the thin film experiment was further concentrated by passing it through a second stage RO system. This second stage test indicated that 50% of the original rejectate could be recovered as permeate at ClO_4^- levels of 17 to 18 μg/L. The rejectate from the second stage test contained ClO_4^- at a concentration of 7,900 μg/L. An additional test was conducted using ion exchange as a potential permeate polishing technique. It was demonstrated that non-detect levels of ClO_4^- (<4 μg/L) were achievable when RO permeate samples with up to 38 μg/L of ClO_4^- were applied. Additional experiments were also conducted to show that the RO rejectate could be successfully treated using biological techniques. Although a recovery rate of up to 80% was demonstrated in the laboratory, it was noted that silica levels in JPL groundwater (at 33.1 mg/L) may limit recovery rates during full-scale operation. At an initial recovery of 80%, silica levels in the first pass rejectate would be 165 mg/L. At a second stage recovery of 50%, silica levels would further increase to more than 330 mg/L. These levels are above the solubility threshold and would result in scaling and membrane fouling. To avoid damaging the membranes during full-scale operation, the overall recovery rate would have to be lowered or softening pretreatment would be needed (U.S. Filter, 1999).

Table F-7. Summary of JPL RO Test Results with a Thin Film Composite Membrane

Treatment	Recovery Rate	Amount Recovered	ClO_4^- in Permeate	Rejection Rate	Amount Rejected	ClO_4^- in Rejectate
Thin Film Composite Membrane						
Single Pass RO	80%	80 gpm	12 to 16 μg/L	20%	20 gpm	3,400 to 4,000 μg/L
Second Pass RO	50%	10 gpm	17 to 18 μg/L	50%	10 gpm	7,900 μg/L
Total	90%	90 gpm	12 to 18 μg/L	10%	10 gpm	7,900 μg/L
Cellulose Acetate Membrane						
Single Pass RO	80%	198.1 mL/min	640 to 680 μg/L	20%	787.4 mL/min	1,600 μg/L

Conclusions

The primary advantage of RO treatment is that it is a commercially available technology that has demonstrated effectiveness for ClO_4^- removal. However, it is unlikely that RO would be appropriate for ex situ groundwater treatment at JPL. The cost-effectiveness of this technology is limited both by membrane fouling issues and by the large volume of waste brine that must be treated and/or disposed. At

the JPL site, RO brine production was on the order of 10% of total influent flow compared to 0.2% for the competing ISEP^{+TM} process. This treatment approach was not retained for further consideration at JPL.

Granular Activated Carbon Adsorption

GAC adsorption involves the accumulation of chemicals in the aqueous phase onto the solid surface of carbon particles. This accumulation occurs as the attractive forces at the carbon surface overcome the attractive forces of the water. Granular activated carbon is typically an excellent adsorbent due to its high surface area to volume ratio. However, the magnitude of adsorption by GAC is compound specific and several researchers including Cannon and Na (2000) and AWWARF (2001b) have found that ClO_4^- is only weakly adsorbed by GAC and that rapid breakthrough can be expected.

GAC Case Study at Crafton-Redlands Site in California

Cannon and Na (2000) evaluated the ability of GAC to adsorb ClO_4^- at both the field-scale and laboratory scale. They first collected data from 24 GAC contactor vessels that were previously installed at the City of Redlands Texas Street Water Facility to treat chlorinated VOCs. Each vessel contained 20,000 lb of GAC. Twelve vessels were in a lead configuration with each one followed by another GAC vessel in the lag position. The average flow through all of the vessels was 3.6 million gallons per day with a 40-minute contact time in each vessel pair. The groundwater at the site was found to contain between 62 and 138 μg/L of ClO_4^-. Cannon and Na demonstrated that ClO_4^- was being removed by the GAC canisters to non-detect levels (<4 μg/L). However, this removal was relatively inefficient. It was determined that in order to sustain ClO_4^- removal, the GAC canisters would have to be changed out every six weeks compared to every eighteen months as necessary for chlorinated solvent removal alone. In addition to the field investigation, several laboratory tests were attempted to improve the adsorptive capacity of GAC and to effect chemical regeneration of the GAC beds in place. Through the preloading of iron and an organic complex solution on the GAC, Cannon and Na (2001) were able to demonstrate an increase of the adsorptive capacity from 0.236 to 0.336 mg ClO_4^-/g GAC. The authors were also able to restore 50% to 74% of the GAC adsorptive capacity in place by washing it with an anionic reducing compound. The authors predicted that they could extend the life of the carbon by up to 100 days, but this still does not approach the 18-month regeneration time for organic loading alone (Cannon and Na, 2000).

GAC Case Study by AWWARF

As part of an AWWARF study, researchers investigated the ability of granular activated carbon to remove ClO_4^- using virgin GAC, GAC impregnated with Cu and Zn, GAC mixed with solids such as Fe, Zn, and Al, and an ozone-hydrogen peroxide GAC process. The results of the study indicated that ClO_4^- removal could not be attributed to ClO_4^- reduction at the GAC surface, but was due primarily to ion exchange processes. The virgin GAC used in the study was shown to have only a low ion exchange capacity for ClO_4^- (0.172 mg ClO_4^-/g GAC). The modified GAC experiments also revealed that ion exchange was the primary ClO_4^- removal mechanism. The experiments using ozone and ozone plus hydrogen peroxide indicated that no ClO_4^- reduction had occurred. ClO_4^- treatment was only found to be successful in biologically active carbon with the addition of an electron donor (AWWARF, 2001).

GAC Case Study at Jet Propulsion Laboratory in California

ClO_4^- removal by GAC was tested during the preliminary stages of the JPL groundwater treatability study. The data indicated that adsorption did occur, but to a lesser extent than was observed with ion exchange resins, and that the interim action level (18 μg/L at the time) was not consistently met (Foster Wheeler, 2000).

Conclusions

Due to its low adsorptive capacity for ClO_4^-, GAC is not likely to be an economically feasible alternative for ClO_4^- treatment at JPL. This treatment approach was not retained for further consideration at JPL.

Potential chemical treatment methods reported in the literature for ClO_4^- include chemical reduction, catalytic reduction, electrochemical reduction, photochemical reduction, and precipitation.

Chemical Reduction

According to Urbansky (1999), ClO_4^- cannot be reduced with the chemical compounds commonly used in the water and wastewater treatment industry including thiosulfate ($S_2O_3^{2-}$), sulfite (SO_3^{2-}) or elemental metals (e.g., Fe, Zn, Cu). During laboratory treatability testing conducted at JPL, it was demonstrated that ascorbic acid, sodium sulfite, sodium thiosulfite, and sodium dithionite were not able to effect any reduction in a 1 g/L ClO_4^- solution (Foster Wheeler, 2000). Some inorganic species can reduce ClO_4^- in an aqueous solution including titanous ions (Ti^{3+}), molybdenum species (Mo[III]), and ruthenous ions (Ru^{2+}). However, the kinetics of the reactions are extremely slow (half-lives of hours to days) which makes these processes impractical for implementation in water treatment (Earley et al., 2000). This treatment approach was not retained for further consideration at JPL.

Catalytic Reduction

Catalysts can be used to overcome the high activation energy needed to effect ClO_4^- reduction. Several authors have reported the successful use of a variety of catalyst types for ClO_4^- treatment including Abu-Omar et al. (2000), Earley et al. (2001), and Aske (2002). Four different nickel and palladium catalysts were also tested for their ability to treat groundwater at JPL.

Abu-Omar et al. (2000) reports that recent laboratory studies with rhenium catalysts show promise in achieving ClO_4^- reduction. Abu-Omar et al. tested three different oxorhenium(V) coordination complexes for their ability to reduce ClO_4^- in the presence of sulfides. Using a variety of sulfide substrates, they were able to demonstrate between 57% and 100% removal of ClO_4^- in the presence of the three different catalyst types. The by-products of this process are sulfoxide and chloride (Abu-Omar et al., 2000).

Earley et al. (2001) has patented the use of a titanium catalyst in the presence of ethanol to treat perchlorate-contaminated groundwater (International Patent Number WO 01/14053A1). Earley et al. (2000) reports that the ClO_4^- reduction reaction rate is increased in a less polar ethanol solution compared to the reduction rate in water alone.

Aske (2000) has patented the use of a series of platinum, palladium, and ruthenium catalysts attached to a zirconium dioxide substrate that are capable of treating ClO_4^-, nitrate, and nitrite in groundwater and brine. Either organic reducing agents such as ethanol or acetic acid can be used to facilitate the reaction, or an inorganic reducing reagent such as hydrogen can be used. When organic reducing reagents are used, the primary by-products of this reaction are chlorate, hypochlorite, and chloride, carbon dioxide, and water. During treatability testing of both groundwater and brines, ClO_4^- effluent levels were demonstrated to be consistently below 5 μg/L and nitrate levels below 10 mg/L. Some groundwater may contain enough reductant (in the form of natural organic matter) to facilitate ClO_4^- removal at the levels of 10 to 100 μg/L typically found in groundwater. However, solutions containing ClO_4^- at levels greater than 5,000 μg/L will require an additional supply of reductant such as ethanol, acetic acid, or other compounds.

The catalyst patented by Aske is used in Calgon Corporation's ISEP^{+TM} process as part of the PNDM. The ISEP^{+TM} process was successfully demonstrated at the pilot-scale at JPL. The PNDM was able to

treat spent brine from the ion exchange units at influent ClO_4^- levels up to 60,000 µg/L and nitrate levels up to 1,000 µg/L. The PNDM unit obtained destruction efficiencies exceeding 99.8% and produced non-detectable levels of ClO_4^- in the brine at <125 µg/L. Ethanol was used as the reductant at JPL. The reaction rate remained constant at 0.0013 sec^{-1}, which indicates that the JPL groundwater did not contain any potential catalyst poisons (Calgon, 1999).

In addition, during the preliminary stages of the JPL groundwater treatability study, four different metal catalysts were examined for their ability to remove ClO_4^- including a Raney Ni 2400 catalyst, a Raney Ni 2800 catalyst, a Pd/Activated Aluminum catalyst and a Pd/Activated Carbon catalyst. The catalysts were tested at influent ClO_4^- levels of 5 and 50 g/L. No appreciable ClO_4^- removal was observed, with the exception of the Pd-impregnated activated carbon. The low level of ClO_4^- removal achieved during this test was attributed to weak adsorption onto the granular activated carbon rather than ClO_4^- reduction (Foster Wheeler, 2000).

Although catalytic processes seem very promising, there are several drawbacks including the cost of expensive precious metal catalysts and the potential need for effluent pretreatment to avoid catalyst fouling (ESTCP, 2000). Compounds that are known catalyst poisons are iodine, organosulfur, organonitrogen, vanadium compounds, and iron compounds (Calgon, 1999). Although catalysts have been employed at the field scale as part of the ISEP^{+TM} process at JPL and other sites, it is unclear whether catalysts would be cost-effective as a stand-alone technology. Catalysts may be more cost-effective when paired with a technology such as ion exchange or reverse osmosis. These processes can concentrate the ClO_4^- influent stream and therefore reduce the volume of water that must be treated in the catalytic unit. Due to the documented higher level of expense compared to biological treatment, this treatment approach (as implemented in the ISEP^{+TM} treatment process) was not retained for further consideration as part of an expanded treatability study at JPL.

Electrochemical and Photochemical Reduction

ClO_4^- in an aqueous solution can be reduced to chloride using either electrochemical or photochemical electrode technologies. The American Water Works Association Research Foundation has demonstrated both of these technologies at the laboratory-scale (AWWARF, 2001a). AWWARF researchers tested the use of titanium-dioxide-coated electrodes to apply an electric current directly to perchlorate-impacted water. Other researches have used electrodes coated with platinum, tungsten, carbide, ruthenium, aluminum, and carbon doped with trivalent chromium or aluminum oxide (Urbansky, 1999). The study involved the use of a two-chambered batch reactor system in which the cathodic and anodic chambers were separated by an ion exchange membrane. Initial ClO_4^- concentrations in the study ranged from 50 µg/L to 5,000 mg/L. Reduction of ClO_4^- ranged from 1% at the highest concentration and up to 35% at the lowest concentration. Although electrochemical reduction has been used for metal-plating and brine electrolysis in industry, it is not currently a practical technology for drinking water treatment and further research is needed. Issues include the competition among anions for active sites on the electrode surface (e.g., sulfate and chloride are more strongly sorbed than ClO_4^-) and the fact that the reaction slows with time as chloride sorbs onto the electrode (AWWARF, 2001a). Urbansky (1999) also reports that electrode corrosion, the loss of surface chemical reactivity over time, and natural organic matter adsorption are the primary challenges to full-scale implementation of this technology. AWWARF researchers also tested the use of titanium-dioxide-coated electrodes to reduce ClO_4^- in the presence of ultraviolet light. At an initial concentration of 5,000 mg/L ClO_4^-, photochemical reduction ranged from 4% to 18% (AWWARF, 2001a). In addition, Gurol and Kim (1999) have reported successful reduction of ClO_4^- with metallic iron in the presence of ultraviolet light under anoxic conditions. During their laboratory experiment, more than 99% of ClO_4^- was reduced to chloride. The experiments were carried out in an unbuffered neutral solution with 1,000 µg/L of ClO_4^- and 100 g/L of elemental iron. The UV

intensity ranged from 0.6 to 0.9 W/cm^2 (Gurol and Kim, 1999). In general, photochemical reduction with electrodes has the same challenges to full-scale implementation as electrochemical reduction (AWWARF, 2001a) and overall, the photochemical reduction process appears to be insufficiently developed and not ready for field-scale project implementation. This treatment approach was not retained for further consideration at JPL.

Precipitation

Chemical precipitation involves the addition of chemicals to convert a soluble compound into an insoluble solid that is subsequently removed by sedimentation or filtration. Urbansky (1998) reports that nitron ($C_{20}H_{16}N_4$) can be used to precipitate a low solubility nitron-hydrogen ClO_4^- salt ($HNitClO_4$). The solubility of this salt is 0.19 mM. No laboratory or field scale studies of this treatment method were identified and the use of the nitron reagent is reportedly cost-prohibitive (Urbansky, 1998). Mower (1995) has also proposed ClO_4^- concentration by water evaporation in a stripping tower and precipitation of ClO_4^- with potassium as $KClO_4$ (U.S. Patent Number 5,382,265). Precipitation methods are typically best suited to the treatment of very highly concentrated wastes and it is not clear that any of these precipitation methods could achieve removal of ClO_4^- to levels less than 4 μg/L. This treatment approach was not retained for further consideration at JPL.

Phytoremediation has been suggested as a potential mechanism for degrading perchlorate in soil systems. Phytoremediation may occur by phytoextraction (accumulation in the branches and leaves), phytodegradation, or rhizotransformation (degradation in the root sphere primarily due to microbial activity). Although many plants have shown the ability to accumulate perchlorate, some plants can drive perchlorate degradation completely to chloride. Nzengung and Wang (2000) found that willow trees could degrade 100 mg/L of perchlorate in 53 days, and that minced spinach and tarragon leaves could degrade 7 mg/L of perchlorate in 30 days. There were no lag times for perchlorate degradation in either experiment. Perchlorate degradation by plants was found to occur in two stages (Nzengung and Wang, 2000). The first stage consisted of an initial uptake of perchlorate proportional to the water uptake by the plant, and a slow transformation of perchlorate to chloride in the plant tissues. The second stage was characterized by a rapid removal of perchlorate by degradation in the root zone with little perchlorate taken up (Xu et. al., 2003)

The thermal destruction of ClO_4^- in wastewaters has been studied by Li and Coppola (1999) and Thomason et al. (1995). Thermal treatment was also tested during the preliminary JPL groundwater treatability tests. In a series of laboratory tests, Li and Coppola demonstrated almost complete decomposition of ClO_4^- ions in solution with noncatalytic hydrothermal (high pressure) and thermal (low pressure) treatment methods. For this study, a surrogate ion exchange brine was used as the influent and consisted of a 7 wt% NaCl brine with 800 mg/L of nitrate and 50 mg/L of ClO_4^-. Thermal decomposition testing was conducted in both a continuous-flow reactor system and a batch reactor. Several different amendments were tested for their ability to lower the decomposition temperature and/or their ability to sorb and concentrate ClO_4^-. The amendments tested included ferric and ferrous salts, ferric chloride, carbon, metal oxide, clay, and various polymers. The presence of ferric or ferrous salts was found to reduce the ClO_4^- decomposition temperature to 170°C compared to 600°C without the additive. The other additives tested did not substantially improve the system performance (Li and Coppla, 1999). Thomason et al. (1995) has demonstrated the destruction of ClO_4^- using supercritical water oxidation at approximately 374°C and pressures of 22.1 MPa. Thermal decomposition was also tested during the JPL treatability test using a 100-mL batch of JPL groundwater that was amended with 0.5 g of glucose and boiled for ten minutes. The 5 g/L of ClO_4^- in the groundwater did not thermally decompose during this test (Foster Wheeler, 2000). The temperature at which the sugar water solution began to boil was not reported. The optimal temperature for ClO_4^- decomposition may not have been achieved. In general, the high temperatures and pressures required for successful thermal treatment would likely limit the cost-effectiveness of these approaches at the full-scale. This treatment approach was not retained for further consideration at JPL.

Based on this literature review, only a select number of the available ClO_4^- treatment technologies should be retained for further consideration for the expanded treatability study at JPL. The conclusions of this literature review are as follows:

- It appears that use of the FBR configuration for ex situ biological treatment is favorable given its better track record for effectiveness, reliability, and control as demonstrated by the successful operation of several full-scale groundwater treatment systems and a pilot-scale system at JPL.

- Although the results from numerous in situ biological treatment case studies are encouraging, several issues need to be resolved regarding the application of this technology at JPL. The primary issue is the feasibility of delivering amendments in a cost-effective manner given the aerial extent and depth of the ClO_4^- groundwater plume at JPL.

- Ion exchange is a commercially viable option and may be cost-effective based on site-specific economic considerations. The need for further destruction and/or disposal of the regenerant brine may limit the cost-effectiveness of this option.

REFERENCES

Abu-Omar, M.M., L.D. McPherson, J. Aria, and V.M. Bereau. 2000. "Clean and Efficient Catalytic Reduction of Perchlorate." *Angew. Chem. Int. Ed.,* 39(23): 4310-4313.

American Water Works Association Research Foundation. 2001a. *Assessment of the Electrochemical Reduction of the Perchlorate Ion*. AWWA Research Foundation and the American Water Works Association. Denver, CO.

American Water Works Association Research Foundation. 2001b. *Removal of Bromate and Perchlorate in Conventional Ozone/GAC Systems*. AWWA Research Foundation and the American Water Works Association. Denver, CO.

ARA, Applied Research Associates

ARA. 2003. Web Site link available at http://www.ara.com.

ARA. 2000. *Biodegradation of Perchlorate in Reverse Osmosis (RO) Rejectates from Treatment of Groundwater*. Prepared for Foster Wheeler Environmental Corporation, Costa Mesa, CA.

Arcadis, Geraghty, and Miller. 2001. *Ninety Day Progress Report: Pilot Study of In-Situ Reactive Zone Technology at Aerojet GET B, Rancho Cordova, California*. Prepared for Aerojet in Sacramento, CA. U.S. EPA Region 9 Superfund Records Center No. 1615-02529.

Aske, J.R. 2002. "Process for Destroying Contaminants in Contaminant Containing Aqueous Streams and Catalysts Used Therefor." United States Patent Number 6,419,837 B1. July 16.

AWWARF, see American Water Works Association Research Foundation

Batista, J., and J. Liu. 2001. "Biological Perchlorate Removal from Drinking Waters Incorporating Microporous Membranes." In A. Leeson, B.M. Peyton, J.L. Means, and V.S. Magar (eds.) *Bioremediation of Inorganic Compounds*, Monterey, California. Battelle Press, Columbus, OH. Vol 6(9).

Burge, S., and R. Halden. 1999. *Nitrate and Perchlorate Removal from Groundwater by Ion Exchange Pilot Testing and Cost Analysis*. Lawrence Livermore National Laboratory, Livermore, CA. UCRL-ID-135639.

California, EPA, 2004. " Perchlorate Contamination Treatment Alternatives" Report Prepared by the Office of Pollution Prevention and Technology Development, Department of Toxic Substances Control, California Environmental Protection Agency.

Calgon. 1999. *Final Report for Removal of Perchlorate and Other Contaminants from Groundwater at NASA JPL.* Prepared for NASA JPL, Pasadena, CA.

Cannon, F.S., and C. Na. 2000. "Perchlorate Removal Using Tailored Granular Activated Carbon and Chemical Regeneration." Presented at the Perchlorate Workshop of the Pollution Prevention Technology Transfer Conference of the Joint Armed Services, San Antonio, TX. August 23-24.

Case, T., 2003. Perchlorate Removal: Evaluating Treatment options" American Water Works Association Research Foundation Report.

Clark, R., M. Kavanaugh, P. McCarty, and R.R. Trussel. 2001. *Review of Phase 2 Treatability Study Aerojet Facility Rancho Cordova, California*. Prepared for Aerojet. July.

Coates, J.D., U. Michaelidou, and S.M. O'Connor. 2000. "The Diverse Microbiology of Per(chlorate) Reduction." *Perchlorate in the Environment*. (Proceedings of the American Chemical Society, Division of Environmental Chemistry Symposium on Perchlorate in the Environment, August 1999). Edited by E.T. Urbansky. Kluwer Academic/Plenum Publishers, NY.

Cox, E.E., E. Edwards, and S. Neville. 2000. "In Situ Bioremediation of Perchlorate in Groundwater." *Perchlorate in the Environment.* (Proceedings of the American Chemical Society, Division of Environmental Chemistry Symposium on Perchlorate in the Environment, August 1999). Edited by E.T. Urbansky. Kluwer Academic/Plenum Publishers, NY.

Cox, E.E., M. McMaster, and S.L. Neville. 2001. "Perchlorate in Groundwater: Scope of the Problem and Emerging Remedial Solutions." In *Proceedings of the 36th Annual Engineering Geology and Geotechnical Engineering Symposium*, Las Vegas, Nevada (pp. 27-32). Idaho State UP, Pocatello, ID.

Cox, E.E. 2002. "In Situ Remediation of Groundwater and Soil Contaminated with Perchlorate and NDMA." *Perchlorate and NDMA in Groundwater: Occurrence, Analysis, and Treatment.* Groundwater Resources Association of California. Baldwin Park, CA. April 17.

DHS, Department of Health Services

Department of Health Services. 2002. Letter to D.E. Vanderkar from R.H. Sakajl Regarding Conditional Acceptance of Biological Treatment (Fluidized Bed Reactors) for the Removal of Perchlorate During Drinking Water Production. April 2, 2002

Earley, J.E., G.A. Amadei, and D.E. Tofan. 2001. "Catalytic System and Method for Reducing Perchlorate Ion." World Intellectual Property Organization Publication Number WO 01/14053 A1.

Earley, J.E., D.C. Tofan, and G.A. Amadei. 2000. "Reduction of Perchlorate Ion by Titanous Ions in Ethanolic Solution." *Perchlorate in the Environment*. (Proceedings of the American Chemical Society, Division of Environmental Chemistry Symposium on Perchlorate in the Environment, August 1999). Edited by E.T. Urbansky. Kluwer Academic/Plenum Publishers, NY.

Environmental Security Technology Certification Program. 2000. *ESTCP Cost and Performance Report: Ammonium Perchlorate Biodegradation for Industrial Wastewater Treatment*. Prepared for U.S. Department of Defense. June.

ESTCP, see Environmental Security Technology Certification Program

Evans, P., A. Chu, S. Liao, S. Price, M. Moody, D. Headrick, B. Min, and B. Logan. 2002. *Pilot Testing of a Bioreactor for Perchlorate-Contaminated Groundwater Treatment*. In A.R. Gavaskar and A.S.C. Chen (eds.), *Remediation of Chlorinated and Recalcitrant Compounds*, 2002 Proceedings of the Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California. Battelle Press, Columbus, OH. ISBN 1-57477-132-9.

Foster Wheeler. 2000. *Draft Feasibility Study Report for Operable Units 1 and 3: On-Site and Off-Site Groundwater*. Prepared for NASA JPL. January.

Geosyntec. 2001. *Workplan for a Pilot Test of the Radial Biobarrier Design for In Situ Bioremediation of Perchlorate in Groundwater, Former GET F Sprayfield.* Prepared for Aerojet Environmental Remediation, Rancho Cordova, CA. May. U.S. EPA Region 9 Superfund Records Center No. 1615-02486.

Geosyntec. 2002. *Final Technical Report for In Situ Bioremediation of Perchlorate Impacted Groundwater*. Prepared for the Strategic Environmental Research and Development Program. June.

Giblin. T., D. Herman, and W.T. Frankenberger. 2000. "Removal of Perchlorate from Ground Water by Hydrogen-Utilizing Bacteria." *J. Environ. Qual., 29*: 1057-1062.

Gingras, T.M., and J.R. Batista. 2002. "Biological Reduction of Perchlorate in Ion Exchange Regenerant Solutions Containing High Salinity and Ammonium Levels." *Journal of Environmental Monitoring, 4*(1): 96-101.

Gillogly, T., Lehman, G., Lee, A., Clifford, D., Deborah, R., Lin, X., 2003. " Biological, Chemical and Electrolytic Ion Exchange Brine Treatment for Perchlorate and Nitrate Removal" Water Quality Technology Conference, Philadelphia, PA, Nov 2-6, 2003.

Gillogly, T., Lehman, G., Lee, A., Clifford, D., Deborah, R., Lin, X., 2004. " Biological, Chemical and Electrolytic Ion Exchange Brine Treatment for Perchlorate and Nitrate Removal" Water Quality Technology Conference, Philadelphia, PA, Nov 2-6, 2003.

Gisch, D., 2003. " Anion exchange resins remove perchlorate from groundwater" *Water and Wastewater International* V 18, n3, p 10.

Gu, B., Yee-Kyoung, K. and G.M. Brown. 2002. "Treatment of Perchlorate Contaminated Groundwater Using Highly Selective, Regenerable Ion-Exchange Technology: A Pilot-Scale Demonstration." *Remediation* Vol. 12, No. 2, pp. 51-68.

Gu, B., Brown, G. M., Alexandratos, S.D., Ober, R., and Patel V. 1999. "Selective Anion Exchange Resins for the Removal of Perchlorate from Groundwater" *Report prepared by Oak Ridge National Laboratory* available at clu-in.org/download/ contaminantfocus/perchlorate/ORNL1.pdf

Guarini, B. 2002. "Ex-Situ Technologies for the Removal of Perchlorate and NDMA from Water." *Perchlorate and NDMA in Groundwater: Occurrence, Analysis, and Treatment.* Groundwater Resources Association of California. April 17. Baldwin Park, CA.

Gurol, M., and K. Kim. 1999. "Investigation of Perchlorate Removal in Drinking Water Sources by Chemical Methods." *Perchlorate in the Environment*. (Proceedings of the American Chemical Society, Division of Environmental Chemistry Symposium on Perchlorate in the Environment, August 1999). Edited by E.T. Urbansky. Kluwer Academic/Plenum Publishers, NY.

Ground Water Remediation Technology Analysis Center. 2001. *Technology Status Report Perchlorate Treatment Technologies*. First Edition. TS-01-01.

GWRTAC, see Ground Water Remediation Technology Analysis Center.

Harding ESE. 2001. *Final Phase 2 Treatability Study Report, Aerojet GET E/F Treatment Facility Sacramento, California*. Prepared for U.S. EPA Region 9. September.

Harding Lawson Associates. 1999. *Final Phase 1 Treatability Study Report: Perchlorate in Groundwater, Baldwin Park Operable Unit, San Gabriel Basin*. Prepared for Baldwin Park Operable Unit Steering Committee. U.S. EPA Region 9 Superfund Records Center No. 47502. April 12.

Hatzinger, P.B. 2000. *Biotreatment of Perchlorate in Groundwater*. Available at: https://www.denix.osd.mil/denix/Public/Library/Water/Perchlorate/Technology/Envirogen_Bio_ SERDP ppt.

Hatzinger, P.B., M.D. Whittier, M.D. Arkins, C.W. Bryan, and W.J. Guarini. 2002. "In-Situ and Ex-Situ Bioremediation Options for Treating Perchlorate in Groundwater." *Remediation, 12*(2): 69-86.

Herman, D.C., and W.T. Frankenberger Jr. 1999. "Bacterial Reduction of Perchlorate and Nitrate in Water." *J. Environ. Qual., 28*(May-June).

Hunter, W.J. 2001. "In Situ Removal of Perchlorate from Groundwater." In A. Leeson, B.M. Peyton, J.L. Means, and V.S. Magar (eds.) *Bioremediation of Inorganic Compounds*, Monterey, California. Battelle Press, Columbus, OH. Vol 6(9).

Hunter, W.J. 2002. "Remediation of Chlorate Contaminated Water With Barriers Containing Soybean Oil." Submitted for publication in the *Proceedings of The Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California*. May.

Interstate Technology Regulatory Cooperation Workgroup. 1998. *Technical and Regulatory Requirements for Enhanced In Situ Bioremediation of Chlorinated Solvents in Groundwater*. Available at http://www.clu-in.org/download/remed/isb-6.pdf.

ITRC, see Interstate Technology Regulatory Cooperation Workgroup

Koenigsberg and Ward. 2000. *Accelerated Bioremediation of Chlorinated Compounds in Groundwater*. Regenesis Bioremediation Products, San Clemente, CA.

Li, L., and E. Coppola. 1999. *Final Report: Hydrothermal/Thermal Decomposition of Perchlorate. Small Business Innovation Research*. U.S. EPA Grant Number 68D99032.

Logan, B.E. 2001. "Assessing the Outlook for Perchlorate Remediation" *Environmental Science and Technology, 35*(23): 483-487.

Logan, B.E. 1998. *A Review of Chlorate and Perchlorate Respiring Microorganisms. Bioremediation Journal 2*(2): 69-79.

Logan, B.E., H. Zhang, J. Wu, R. Unz, and S.S. Koenigsberg. 2000. "The Potential for In Situ Perchlorate Degradation." In G.B. Wickramanayake, A.R. Gavaskar, J.T. Gibbs and J.L. Means (eds.), *Case Studies in the Remediation of Chlorinated and Recalcitrant Compounds*. Battelle Press, Columbus, OH. pp. 87-92.

Logan, B. E., Wu, J., Unz, R. F. 2001. "Biological Perchlorate Reduction in High-Salinity Solutions" Water Res., Vol. 35, No. 12, pp 3034-3038.

Losi, M.E., V. Hosangadi, D. Tietje, T. Giblin, and W.T. Frankenberger Jr. 2001. "Bioremediation of Perchlorate in Groundwater and Reverse Osmosis Rejectates." In A. Leeson, B.M. Peyton, J.L. Means, and V.S. Magar (eds.) *Bioremediation of Inorganic Compounds*, Monterey, California. Battelle Press, Columbus, OH. Vol 6(9).

McCarty, P.L., L.N. Goltz, G. Hopkins, M.E. Dona, J. Allan, B.T. Kawakami, and T.J. Carrothers. 1998. "Full-Scale Evaluation of In Situ Cometabolic Degradation of Trichlorethylene in Groundwater through Toluene Injection." *Environmental Science and Technology, 32*: 88-100.

McMaster, M.L., and E.E. Cox. 2001. "Successful Field Demonstration of In Situ Bioremediation of Perchlorate in Groundwater." In A. Leeson, B.M. Peyton, J.L. Means, and V.S. Magar (eds.) *Bioremediation of Inorganic Compounds*, Monterey, California. Battelle Press, Columbus, OH. Vol 6(9).

Mower, G.L. 1995. "Perchlorate Removal Process." U.S. Patent Number 5,382,265. January 17.

Najm, I., T. Rhodes, L. Boulos, B. Gallagher, R. Bowcock, C. Williams, and C. Dennis. 1999. "Application of Ion-Exchange Technology for Perchlorate Removal from Drinking Water." In: 1999 Annual Conference Proceedings; American Water Works Association, Chicago, IL. June 20-24.

NZENGUNG, V.A., and WANG, C.H. (2000). Influences on phytoremediation of perchlorate-contaminated water. In E.T. Urbansky, Ed., *Perchlorate in the Environment*. New York:

Kluwer Academic/Plenum Publishers, pp. 219–230.

O'Niell, W., V. Nzengung, and A. Adesida. 1999. "Treatment of Perchlorate Contaminated Water in Microbial Mat, Algae, and EBB-and-Flow Bioreactors." *Case Studies in Remediation of Chlorinated and Recalcitrant Compounds*.

Perlmutter. 2000. "Concept to Pilot-Scale: Ex Situ Biotreatment of Perchlorate-Contaminated Soil and Groundwater." Air and Waste Management Association, 93rd Annual Conference and Exhibition, Salt Lake City, Utah, June 18-22.

Perlmutter, M.W., R. Britto, J.D. Cowan, M. Patel, M. Craig. 2000. "Innovative Technology: In Situ Biotreatment of Perchlorate-Contaminated Groundwater." Proc. Air and Waste Management Association, 93rd Annual Conference and Exhibition, Salt Lake City, Utah, June 18-22, 2000.

Perlmutter, M.W., R. Britto, J.D. Cowan, and A.K. Jacobs. 2001. "In Situ Biotreatment of Perchlorate and Chromium in Groundwater." In A. Leeson, B.M. Peyton, J.L. Means, and V.S. Magar (eds.) *Bioremediation of Inorganic Compounds*, Monterey, California. Battelle Press, Columbus, OH. Vol 6(9).

Rittmann, B.E., R. Nurenberg, T.E. Gillogly, G.E. Lehman, and S.S. Adham. 2002. "Perchlorate Reduction Using the Hollow-Fiber Membrane Biofilm Reactor." Submitted for the Proceedings of the Seventh International Symposium on In Situ and On-Site Bioremediation, Orlando, FL, June 2003.

Sutton, P.M., and M. Greene. 1999. "Perchlorate Treatment Utilizing GAC and Sand Based Biological Fluidized Bed Reactors." Water Environment Federation 72nd Annual Conference and Exposition. New Orleans, LA. October 9-13, 1999. p. 1026-1036.

Thomason, T.B., G.T. Hong, K.C. Swallow, and W.R. Killilea. 1995. *The MODAR Supercritical Water Oxidation Process.* Innovative Hazardous Waste Treatment Technology Series. Volume 1: Thermal Processes.

Togna, P.A., W.J. Guarini, S. Frisch, M. Del Vecchio, J. Polk, C. Murray, and D.E. Tolbert. 2001. "Case Study of Ex-Situ Biological Treatment of Perchlorate Contaminated Groundwater." In A. Leeson, B.M. Peyton, J.L. Means, and V.S. Magar (eds.) *Bioremediation of Inorganic Compounds*, Monterey, California. Battelle Press, Columbus, OH. Vol 6(9).

Tripp, A. R., Clifford D., Roberts, D.J., Cang, Y., Aldrige, L., Gillogly T., Boulos L., 2003. "Treatment of Perchlorate in Groundwater by Ion Exchange Technology" Report prepared for American Water Works Association Research Foundation.

United States Environmental Protection Agency. 1993. *Nitrogen Control Manual.* Office of Research and Development, Washington, DC. EPA/625/R-93/010.

United States Environmental Protection Agency. 2001. *Record of Decision for the Western Groundwater Operable Unit OU-3, Aerojet Sacramento Site, Rancho Cordova, California.* Prepared by U.S. EPA Region 9, San Francisco, CA. July 20.

Urbansky, E.T. 1998. "Perchlorate Chemistry: Implications for Analysis and Remediation." *Bioremediation Journal, 2*(2): 81-95.

Urbansky, E.T. 1999. "Issues in Managing the Risks Associated with Perchlorate in Drinking Water." *Journal of Environmental Management, 56*(2): 79-95.

U.S. Filter. 1999. Removal of Perchlorate from Groundwater Using Reverse Osmosis and Biological Treatment. Prepared for Foster Wheeler Environmental Corporation, Costa Mesa, CA.

Van Ginkel, G.C., A.G. Kroon, G.B. Rikken, and S.W. Kengen. 1998. "Microbial Conversion of Perchlorate, Chlorate, and Chlorite." In: Proceedings of the Southwest Focused Groundwater Conference: Discussing the Issue of MTBE and Perchlorate in Groundwater, pp. 92-95. National Groundwater Association.

Vankatesh, K.R., E.R. Cobes, D.L. Jennings, and N.J. Wagner. 2000. *Process for the Removal and Destruction of Perchlorate and Nitrate from Aqueous Streams.* United States Patent Number 6,066,257. May 23, 2002.

Wagner, N., and C. Drewry. 2002. "Commercial Systems Treating Both High and Low Strength Perchlorate Applications Utilizing Ion Exchange. Available at: https://www.denix.osd.mil/denix/Public/Library/Water/Perchlorate/technology.html

Williams, C. 2002. "Solving the San Gabriel Basin Perchlorate Problem." *Perchlorate and NDMA in Groundwater: Occurrence, Analysis, and Treatment.* Groundwater Resources Association of California, Baldwin Park, CA. April 17.

Xu, J., Song, Y., Min, B., Steinberg, L., and Logan B. 2003. " Microbial Degradation of Perchlorate: Principles and Applications" *Environmental Engineering and Science*, Vol. 20, Number 5, p 405-422.

Zhang, Z., T. Else, P. Amy, and J. Batista. 2001. "Evaluation of In Situ Biodegradation of Perchlorate in a Contaminated Site." In A. Leeson, B.M. Peyton, J.L. Means, and V.S. Magar (eds.) *Bioremediation of Inorganic Compounds*, Monterey, California. Battelle Press, Columbus, OH. Vol 6(9).

ATTACHMENT F1
PERCHLORATE CONTAMINATION TREATMENT TECHNOLOGIES

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
ION EXCHANGE						
Calgon ISEP	System includes multiple anion exchange resinsmounted on a turntable attached to a rotating multi-port valve.	Full Scale-Operational	2500 gpm	La Puenta Valley, CA	~200 µg/L to < 4µg/L	Capital = $2 million Operating Cost= $154/ acre-ft
		Full Scale-Operational	450 gpm	Kerr- McGee, Henderson, Nevada. A calgon ISEP PDM (Perchlorate destruction module) installed and operated for six months. Flow rates varied between 200 to 560 gpm. Maintenance problems caused due to high TDS, hardness and sulfate. Operation was discontinued due to corrosion of heat exchangers	80-100 mg/L to >2 mg/L (D.L. ion specific electrode)	
		Pilot Scale-Planned	4.3 gpm	Baldwin Park, CA.	18-76µg/L to < 4µg/L	
		Full Scale-Planned	7800 gpm	San Gabriel Valley water Company, El Monte, CA		
		Full Scale-Planned	7800 gpm	Valley county water district, Baldwin Park, CA		
		Full Scale-Planned	4000 gpm	City of Pasadena,CA. 3000-3500 gpm system proposed at existing wells next to JPL site; planning stage		
Calgon Anion Exchange	Fixed bed non-regenerable anion exchange resin treatment	Full Scale-Operational	5000 gpm	California Domestic Water company, Whittier, CA; (startup 7/2002)	< 14µg/L to <4µg/L	$125/ acre-ft.
		Full Scale-Operational	5000 gpm	City of Riverside, Ca, Tippecance Treatment	average value of 6.4 ppb to	

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
				Facility;(startup 12/02)	4.6 ppb	
		Full Scale-Operational	2000 gpm	City of Riverside, CA, Gage Treatment Facility (startup 5/03)		
		Full Scale-Operational	2000 gpm	West San Bernadino Water district, Rialto, CA (startup 05/03)		
		Full Scale-Planned	4050 gpm	City of Monterey Park, CA (1/04)		
		Full Scale-Planned	7800 gpm	San Gabriel Water Company, El Monte, CA		
		Full Scale-Operational	>300 gpm	Kerr- McGee, Henderson, Nevada. Pumping rates varied between 300 gpm to 600 gpm.	System influent averages around 30 ppm. Effluent discharge varies from <0.5 ppm and 2 ppm.	
		Full Scale-Planned	2000 gpm	Loma Linda, CA.		
		Full Scale-Operational	850 gpm	Kerr- Mc Gee facility in Nevada. A single pass ion-exchange system was installed to replace the Calgon ISEP system to allow continous treatment of the extracted groundwater.	System influent averages around 300 ppm. Effluent discharge varies from <0.5 ppm and 2 ppm.	
US Filter Anion Exchange	Fixed bed non-regenerable anion exchange resin treatment	Full Scale-Operational	1000 gpm	Aerojet, CA, Sacremento GET D facility	200 ppb to < 4ppb	
		Full Scale-Operational	2000 gpm	Aerojet, CA, Sacremento GET B facility	50 ppb to <4 ppb	

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
		Full Scale-Operational	800 gpm	Aerojet and Boeing (Formerly McDonald Douglas), Sacremento, CA	250 ppb to < 4 ppb	
		Full Scale-Operational	800 gpm	City of Morgan Hill, CA.	<10 ppb to < 4 ppb	
		Full Scale-Operational	2000 gpm	West Valley Water Co., West San Bernadino,CA (startup 005/03)	<10 ppb to <4 ppb	
		Full Scale-Operational	2000 gpm	City of Rialto, CA (startup 08/03)	<10 ppb to < 4 ppb	
		Full Scale-Operational	3500 gpm	City of Colton, CA (startup 08/03)	<10 ppb to < 4 ppb	
		Full Scale-Constructed	5000 gpm	Fontana Union Water Co., Fontana, CA	15 ppb to < 4 ppb	
		Full Scale-Operational	800 gpm	West San Martin Co., West San Martin, CA	17 ppb to < 4 ppb	
Ion Exchange	Originally designed for nitrate removal, anion exchange system achieves perchlorate removal	Full Scale-Operational	10000 gpm	City of Pomona,CA		
SELECTIVE ION EXCHANGE RESINS						
SYBORN IONAC SR-7	Commercially available regenerable resin	Full Scale-Operational	1400 gpd	Lawerence Livermore Laboratory- Building 815 SR-7	10 µg/L to < 4 µg/L	
		Full Scale-Operational	5000 gpd	Lawerence Livermore Laboratory- Building 830 DISS	11 µg/L to < 4 µg/L	
		Full Scale-Operational	1000 gpd	Lawerence Livermore Laboratory- Building 854-PRX	7.2 µg/L to < 4 µg/L	
Purolite A-520 E	Commercially available	Lab Study		Paducah gaseous Diffusion		

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
	regenerable resin			Plant		
		Lab Study		ORNL comparison study for bifunctional resins		
Rohm and Hass Corporation Amberlite PWA-2	Rohm and Hass developed non regenerable NSF 61 certified resin	Full Scale-Operational	2000 gpm	Aerojet, Sacramento,CA	50 ppb to <4 ppb	
Rohm and Hass Corporation Amberlite PWA-55	Commercially available resin	Full Scale-Operational	1000 gpm	W. San Martin Colony and County Wells	15 ppb to <4 ppb	
Oak Ridge National Laboratory (ORNL) and University of Tennessee (UT) Purolite A-530E Bifunctional resin	ORNL and UT developed bifunctional resin which had quaternary ammonium groups with large and small alkyl groups resulting in highly selective resin	Full Scale-Planned	25 gpm	Stringfellow site, Riverside CA.High TDS including sulfate and nitrates make the process tedious and frequent regeneration or changeouts with no brine disposal options	30 ppb to < 4 ppb	
BIOLOGICAL REDUCTION						
Envirogen/US Filter- Envirex fluidized bed reactors (FBR) with GAC media	Fluidized bed reactors with granular activated carbon media. Typically,ethanol is used as the electron acceptor	Full Scale-Operational	5300 gpm	Aeroject, Rancho Cordova	< 4 µg/L	
Applied research Associates, Inc.	Coustom Designed Biological Treatment system	Full Scale-Operational		Thiokol, Brigham City, Utah. Full Scale continously stirred tank reactor biological system operating since December 1997	> 5000 mg/L to 4-400 µg/L	$0.35 to $1.00/gallon
		Designed	825 gpm	Kerr- McGee, Henderson, Nevada.		
Foster Wheeler/ Arcadis Packed Bed Bioreactor	Packed Bed Bioreactor	Pilot Scale		NASA JPL, Pasadena, CA.	<1mg/L to non detect	

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
Pennsylvania State University anaerobic packed bed bioreactor	anaerobic acetate and nutrients-fed packed bed reactor with sand and plastic media; hydrogen reactors	Pilot Scale		Crafton-Redlands Plume,Redlands, CA.	70 µg/L reduced to < 4µg/L	
Eco Mat Hall Reactor	The patented Hall reactor provides an efficient circulation pattern and utilizes a floating porous media, Ecolink, which has a very high surface area to volume ratio.	Commercial	~2 gpm	DOD facility, Southern California.	350 µg/L to < 9 µg/L	$0.50/1000 gallons
Hollow Fiber Membrane Biofilm Reactors	Bruce E. Rittmann of Northwestern University patented a hollow-fiber membrane biofilm reactor that utilizes hydrogen as an electron donor to biologically degrade perchlorate.	Pilot Scale	0.3 gpm	La Puenta, CA.		
IN-SITU BIOLOGICAL TREATMENT						
GeoSyntec Consultants	Groundwater is extracted, then ammended with acetate before being reinjected at an upgradient location. Optimally system is operated and monitored to ensure a closed groundwater recirculation loop.	Pilot Scale - Completed		Aerojet, Sacremento.	12mg/L reduced to < 4µg/L	

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
		Pilot Scale - Completed		AMPAC (formerly Pepcon) facility, Nevada. The electron donor was switched from ethanol to citrate after 3 months due to fouling problems. Nitrates and chlorates are preferentially biodegraded before perchlorate.	After 160 days of operation 500 to 800 ppb reduced to 2 ppb	
Aerojet, Sacremento	Injection of amended water to remediate a perchlorate contaminated groundwater	Pilot Scale - Completed		Several tests have been done		
		Pilot Test - Planned		Horizontal well used to inject ammended water		
		Pilot Test - Planned		Ammended water addition to contaminated aquifer via a percolation pond.		
Groundwater Barrier Trench with cotton seed meal and cotton seed	Groundwater collection trench constructed with composting materials, cotton seed meal and cotton seed.	Full Scale - Operational		Naval Weapons Industrial Reserve Plant, McGregor, Texas.	27,000 µg/L reduced to < 4 µg/L	
NASA JPL Pasadena/Arcadis	Injection of corn syrup or other carbon source as the electron donor to promote biodegradation of perchlorate	Full Scale - Operational		NASA JPL Pasadena, CA.		
Solutions IES	Biologically active permeable barrier- injection of corn syrup or other carbon source as the electron donor to promote biodegradation of perchlorate	Full Scale - Proposed		Edwards AFB.		

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
Los Almos National Laboratory	A multilayer permeable reactive barrier. The PRB incorporates a sequence of four reactive media layers to immobilize or destroy a suite of contaminants present in alluvial groundwater, including Sr-90, Pu-238, 239, 240, Am-241, perchlorate, and nitrate. The four sequential media cells consist of gravel sized scoria, apatite, pecan shells, and cottonseed with an admixture of gravel (biobarrier) and limestone.	Full Scale - Operational		LANL, Mortandad Canyon, NM.	Bench Scale results. Perchlorate reduced from 120 ppb to 35 ppb.	$900,000 to install
GRANULAR ACTIVATED CARBON (GAC)						
Granular Activated Carbon	GAC system initially installed to treat VOC contamination for drinking water supply was later found effective to treat low concentrations of perchlorate	Full Scale - Operational		Crafton-Redlands Plume, City of Redlands, CA.	60 to 138 µg/L influent concentration. Effluent concentration not available right now.	

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
	A liquid phase GAC system	Full Scale - Operational	100 gpm	Edwards Site 113,	Influent perchlorate concentrations were 92 µg/L but the initial reports indicated that the system is ineffective in removing perchlorate.	
	Cocunut carbon to treat low levels	Full Scale Testing Planned		City of Monterey Park, Well 5		
COMPOSTING/ IN SITU TREATMENT (Contaminated Soil)						
GeoSyntec Consultants	Anaerobic composting of perchlorate-contaminated soils	Pilot Demonstration	20 yards	Aerojet, Sacremento, CA.	Maximum detected perchlorate concentration of 4200 mg/kg. Average 23 mg/Kg to about 0.1 mg/Kg in seven days.	
In situ biological treatment	In situ biological treatment of perchlorate contaminated soil using chicken manure, cow manure, and ethanol as suitable carbon sources.	Bench Scale-Completed Full Scale - Planned		Long Horn Army Ammunitions Plant, Texas.	Perchlorate reduced to below detection limit after 10 months.	estimated: $25-50/yard

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
Soil Composting	Soil Composting	Full Scale		Pueblo Army Depot, Colrado.	Results unavailable	
Soil Bioremediation	Anaerobic composting of perchlorate soils	Full Scale and one planned	1500 cubic yards in ful scale operations and 2400 yards planned	Boeing, Santa Susana Field Laboratory, Ventura Co.,CA is in full scale soil bioremediation process and Boeing, Sacremento is planning one.		
Anaerobic Soil Composting	Mixing in compost as nutrient to allow soil microbes to degrade perchlorate under anoxic condition	Planned		United Technologies Corp., located southeast of San Jose, CA.		
Anaerobic Soil Composting	Anaerobic composting	Feasibility Studies		Edwards Air Force Base.		
BIOLOGICALLY ACTIVE CARBON						
Biologically Active Carbon	Biologically active carbon filtration can effectively remove low levels of nitrate and perchlorate under anaerobic conditions with the addition of an electron donor.	Pilot Scale				
MEMBRANE FILTRATION						
Reverse Osmosis	Water is forced though a semi permeable membrane.	No applications		None		

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
Nanofiltration	A partially permeable membrane is used to preferentially separate different fluids or ions. Nanofiltration generally works for particle sizes over 10 angstrongs. Perchlorate ion being 3.5 angstrongs it might not prove to be a very useful technology for perchlorate removal	No applications		None		
Electrodialysis	Water is passed through channels of alternating semi permeable and permeable membranes, while being exposed to an electrical field	Pilot Scale-completed	7.4 gpm	Magna Water Co.,Utah.	Perchlorate removal rates stabilized in the low 70 percent range; higher removal rates (94%) could be achieved with a larger system	$1.10 to $1.50 / 1000 gallons
CHEMICAL REDUCTION						
UV Light/ Zero Valent Iron Reduction	Lab studies indicate that perchlorate can be reduced by iron (FeO) under anoxic conditions and the UV light can accelerate the reaction rate for practical application.	Laboratory Research		As of June 9, 2003, the San Diego office of Technology Transfer was seeking funds to commence six months of field testing to develop a commercial prototype		

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
Titanium +3 Chemical Reduction	Gorgetown University has developed a technique using titanous ions to chemically reduce perchlorate. Several new organic ligands have been developed that have shown to catalyze reduction of perchlorate by titanous ions to titaniun oxide and chloride in acidic aqueous media.	Laboratory Research				
Electrochemical Reduction	A bench scale study of electochemical reduction of perchlorate was conducted using two chambered batch reactor systems.	Laboratory Research				
ELECTROCHEMICAL						
Capacitative Deionization carbon aerogel	Influent water containing salts enters space between two carbon-aerogel electrodes; electrostatic field forces ions into aerogel, where they are held and purified water leaves the space between the electordes.	Research and Development		CDT systems Inc. is planning to install this system at the municipal water treatment plant in Carlsbad, California.		

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
Capacitative Deionization Flow thorough Capacitor	The flow through Capcaitor is made up of alternating electrodes of porous activated carbon. With application of small voltage, dissolved salts in the water moving through the capacitor are attracted to the high surface are carbon and removed. Once the capacitor is fully charged the electrodes are shorted to regenerate the capcitor, causing adsorbed contaminants to be released as a small volume of concentrated liquids	Research and Development		The flow through capacitor technology is covered by a number of patents and Biosource Inc. indicated in May, 2004 that it will be used by the military to purify water and it shall be used in Iraq also.		
PHYTO REMEDIATION						
Willow trees	In bench scale tests willow trees successfully treated water contaminated with perchlorate. Rhizodegradation accounted for most of the removal of perchlorate with little uptake into the plant.	Bench Scale				

Table F1-1: Perchlorate Contamination Treatment Technologies (CA EPA, 2004) (Continued)

Technology & Vendor Name	Technology Description	Scale/Status	Throughput	Projects	Treatment Effectiveness	Costs
Salt Cedar Trees	stalks of the plant picked up significant concentrations of perchlorate per gram tissue	Research				
Contained Wetlands	Lawerence Livermore National Laboratory engineered plants to assimilate or degrade nitrate and perchlorate in water via the interaction of the contaminant with plant roots and their associated rhizosphere microorganisms.	Pilot Study-Completed		A containerized wetland system designed to remove nitrate and perchlorate from groundwater was tested over a seven-month period at Lawerence Livermore National Laboratory	Removal of perchlorate below 4 µg/L	

**NATIONAL ENVIRONMENTAL POLICY ACT OF 1969 (NEPA)
VALUES ASSESSMENT FOR OPERABLE UNIT 1**

CONTENTS

FIGURES

ACRONYMS AND ABBREVIATIONS

ARAR	applicable or relevant and appropriate requirement
ASTDR	Agency for Toxic Substances and Disease Registry
bgs	below ground surface
CAA	Clean Air Act
Cal-EPA	State of California, Environmental Protection Agency
Caltech	California Institute of Technology
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	Code of Federal Regulations
CCl_4	carbon tetrachloride
DCE	1,1-dichloroethene
DOJ	Department of Justice
DTSC	Department of Toxic Substances Control
FBR	fluidized bed reactor
FFA	Federal Facilities Agreement
Freon 113	1,1,2-trichloro-1,2,2-trifluoroethane
FS	Feasibility Study
FWEC	Foster Wheeler Environmental Corporation
HHRA	human health risk assessment
JPL	Jet Propulsion Laboratory
LGAC	liquid-phase granular activated carbon
MCL	maximum contaminant level
NA	no action
NAAQS	National Primary and Secondary Ambient Air Quality Standard
NASA	National Aeronautics and Space Administration
NAVFAC	Naval Facilities Engineering Command
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEPA	National Environmental Policy Act of 1969
NPL	National Priorities List
OU	operable unit
PTO	permit to operate

RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
ROD	Record of Decision
RWQCB	Regional Water Quality Control Board
SCAQMD	South Coast Air Quality Management District
SIP	State Implementation Plan
SVE	soil vapor extraction
SWRCB	State Water Resources Control Board

| TCE | trichloroethene |

| EPA | U.S. Environmental Protection Agency |

| VOC | volatile organic compound |

1: INTRODUCTION

This National Environmental Policy Act of 1969 (NEPA) Values Assessment accompanies the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) remedial documentation for Operable Unit 1 (OU-1) at the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL). The Council on Environmental Quality (CEQ) and the Department of Justice (DOJ) have advised that federal agencies should integrate NEPA values into the CERCLA process when feasible and appropriate (DOJ, 1995).

1.1 Purpose and Need

Under CERCLA, NASA must determine the appropriate action to remediate volatile organic compounds (VOCs) and perchlorate in source area groundwater at JPL. This document accompanies CERCLA documentation for OU-1 and serves to integrate NEPA values into the CERCLA process for the response action.

1.2 Applicable Statutes and Regulations

This section discusses the federal, state, and local environmental statutes and regulations that are applicable or relevant and appropriate requirements (ARARs) to the response action at OU-1. Section 13.2 of the Interim ROD summarizes the ARARs associated with the limited-scope interim action.

1.2.1 National Environmental Policy Act of 1969, as Amended

This document is prepared in compliance with NEPA, as amended, and the Council on Environmental Quality Regulations for Implementing NEPA (40 CFR Parts 1500-1508). It is prepared to comply with NEPA through the assessment of selected NEPA values associated with the response action for OU-1 at JPL.

1.2.2 Other Federal Regulations

A Federal Facilities Agreement (FFA) under CERCLA Section 120 was executed in 1992 by NASA, EPA Region IX, State of California, Environmental Protection Agency (Cal-EPA) Department of Toxic Substances Control (DTSC), and the Regional Water Quality Control Board (RWQCB), Los Angeles Region (EPA, 1992). The FFA lists JPL as a Resource Conservation and Recovery Act (RCRA)/CERCLA site requiring further evaluation using an investigation/assessment process that integrates and combines the RCRA Facility Investigation Process with the CERCLA Remedial Investigation (RI) process to determine the actual or potential impacts.

Federal environmental regulations considered to be ARARs were identified as part of the CERCLA process. These ARARs will be used to establish standards, consistent with the National Oil Hazardous Substance and Pollution Contingency Plan (NCP), for any remedial actions at OU-1 unless waived.

1.2.3 State and Local Regulations

State and local environmental regulations that are considered ARARs have been identified and will be used to establish standards that are consistent with the NCP for any remedial actions at JPL OU-1, unless waived.

2: PROPOSED ACTION AND ALTERNATIVES

During the RI of OU-1, the following four VOCs were detected frequently at elevated concentrations in groundwater samples: carbon tetrachloride (CCl_4); tricholorethene (TCE); tetrachloroethene (PCE) and 1, 1-dichloroethene (1, 1-DCE). In addition, perchlorate was detected frequently at elevated levels. The *Final Remedial Investigation Report for Operable Unit 1 and 3 On-site and Off-site Groundwater* (Foster Wheeler Environmental Corporation [FWEC], 1999) contains detailed information and data for all of the environmental groundwater samples taken in the characterization of OU-1.

The highest concentrations of carbon tetrachloride and perchlorate at the JPL site are located in the north-central portion of the JPL facility, which is referred to as the "source area." The source area is the location where the majority of chemicals are dissolved in the groundwater, and is defined as an eight-acre by 100-ft-thick portion of the aquifer.

In the late 1990s and early 2000s, NASA conducted pilot testing of several technologies to address dissolved perchlorate in source area groundwater. The technologies tested included reverse osmosis, a fluidized bed reactor (FBR), packed bed reactors, in situ bioremediation, and ion exchange. Due to the depth and extent of the chemicals in groundwater, in situ (below ground) treatment is not cost-effective at the JPL facility; therefore, groundwater must be pumped from the ground, treated above ground, and reinjected.

NASA installed a demonstration treatment plant located on JPL in the source area in early 2005. The demonstration study consists of two extraction wells, two injec¬tion wells, liquid-phase granular activated carbon (LGAC) treatment to remove VOCs, and a FBR to remove perchlorate. This system has been successful in the demon¬stration phase and the Interim ROD documents expansion and continued opera¬tion of the demonstration system as the response action.

The source area treatment facility is located on NASA Property. The ex situ biological treatment of perchlorate and LGAC treatment of VOCs will be operated until the performance objectives are achieved (see Section 11.4 of the Interim ROD).

A groundwater monitoring program, currently in place, will be used to track VOC and perchlorate concentrations and the areal extent of VOCs and perchlorate in groundwater over time. The monitoring program will consist of the periodic collection and analysis of groundwater samples from existing monitoring wells. This program will be used evaluate the treatment system's effectiveness and progress toward achieving the remedial action objectives (RAOs) discussed in the Interim ROD.

NASA expects that the selected alternative, ex situ biological treatment of perchlorate and LGAC treatment of VOCs, will satisfy the statutory requirements in CERCLA section 121(b) that the selected alternative:

- Be protective of human health and the environment

- Comply with ARARs

- Be cost-effective

- Use permanent solutions and alternative treatment technologies to the maximum extent practicable

- Satisfy the statutory preference for treatment as a principal element, or justify not meeting the preference.

The other alternative considered for OU-1 was "no further action" (NFA). This alternative includes groundwater monitoring as part of the selected alternative, but there would be no treatment technologies to remediate VOCs and perchlorate for on-site groundwater. The No Action alternative is required by the NCP and serves as the baseline for comparison for the other alternatives.

3: AFFECTED ENVIRONMENT

The JPL site is located within the San Gabriel Valley, in the eastern part of Los Angeles County. It is located between the city of La Cañada Flintridge and the unincorporated city of Altadena, CA, northeast of the 210 Foothill Freeway near Pasadena, CA.

JPL is situated on a south-facing slope along the base of the southern edge of the east-west trending San Gabriel Mountains at the northern edge of the metropolitan Los Angeles area. The Arroyo Seco, an intermittent streambed, lies immediately to the east and southeast of JPL. Within the Arroyo Seco is a series of surface impoundments used as surface water collection and spreading basins for groundwater recharge. Residential development, an equestrian club (Flintridge Riding Club), and a Los Angeles County Fire Department Station (Fire Camp #2) border the JPL along its southwestern and western boundaries. Residential development also is present to the east of JPL, along the eastern edge of the Arroyo Seco.

3.1 Land Use

JPL comprises about 176 acres of land. Of these 176 acres, about 156 acres are federally owned. The remaining land is leased for parking from the City of Pasadena and the Flintridge Riding Club. The main developed area of JPL is the southern half, which can be divided into two general areas, the northeastern early-developed area and the southwestern later-developed area. Most of the northern half of JPL is not developed because of steeply sloping terrain.

Currently, the northeastern early-developed part of JPL is used for project support, testing, and storage. The southwestern later-developed part is used mostly for administrative, management, laboratory, and project functions. Further development of JPL is constrained because of steeply sloping terrain to the north, the Arroyo Seco to the south and east, and residential development to the west.

Located at the northern boundary of JPL is the Gould Mesa area. This area has widely separated small buildings and is used primarily for antenna testing. The distance between buildings is a result of the terrain and the need to isolate transmitting and receiving equipment. The relatively steep mountainside between Gould Mesa and the developed area at JPL is unpopulated.

Presently, more than 150 structures and buildings occupy JPL. Total usable building space is approximately 1,330,000 ft^2. Figure D-2 is a facility map for JPL.

The primary land use in the areas surrounding JPL is residential and light commercial. Industrial areas, such as manufacturing, processing, and packaging, are limited. The closest residential properties are those located along the western fence line of JPL. The nearest off-facility buildings are the Flintridge Riding Club and Fire Camp #2, both located approximately 100 yards from the southern border of JPL. The total number of buildings within two miles of JPL is about 2,500, primarily residential and community (e.g., schools, day-care centers, churches).
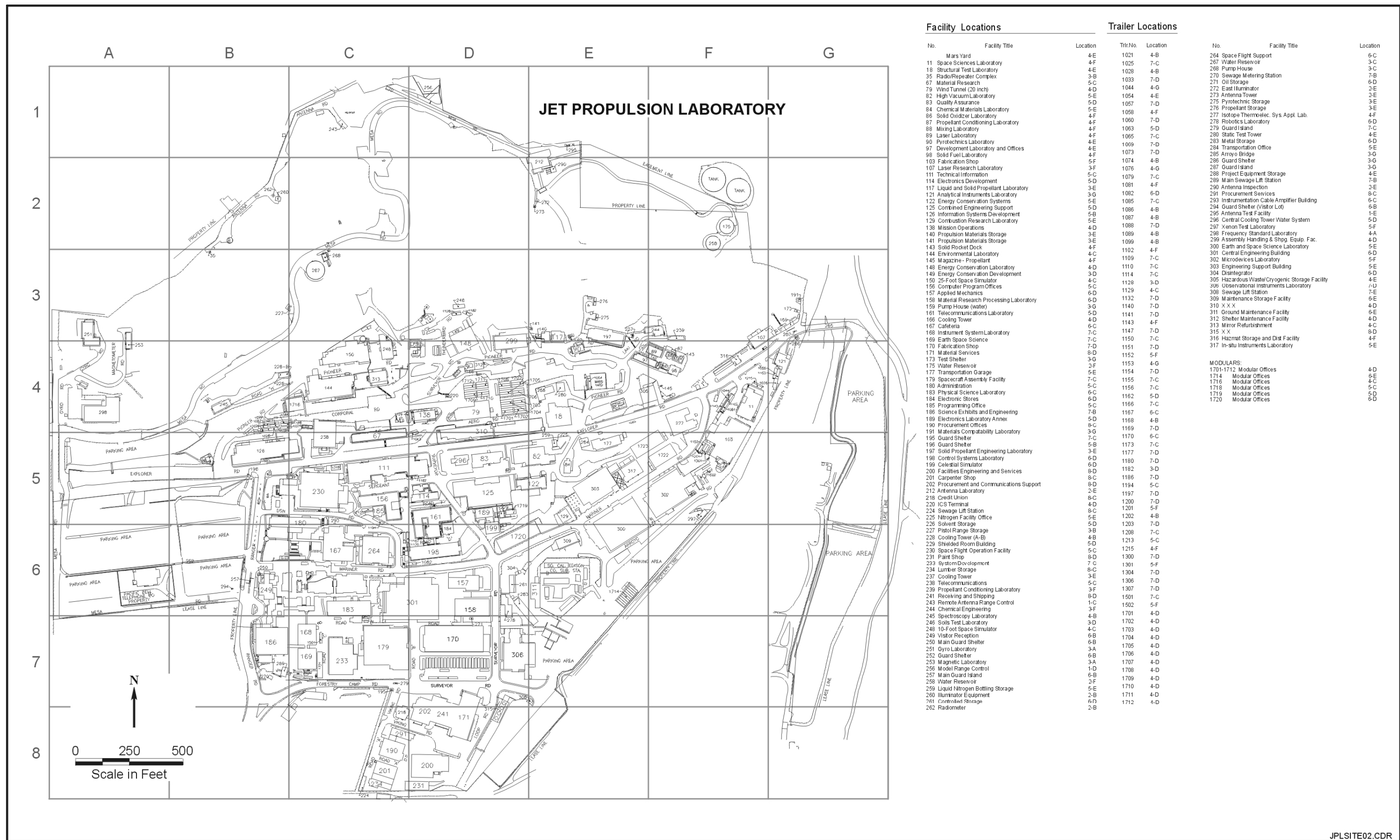
JET PROPULSION LABORATORY

Figure 1. Facility Map of JPL

Facility Locations

No.	Facility Title	Location
	Mars Yard	4-E
11	Space Sciences Laboratory	4-F
18	Structural Test Laboratory	4-E
35	Radio/Repeater Complex	3-B
67	Material Research	5-C
79	Wind Tunnel (20 inch)	4-D
82	High Vacuum Laboratory	5-E
83	Quality Assurance	5-D
84	Chemical Materials Laboratory	4-F
86	Solid Oxidizer Laboratory	4-F
87	Propellant Conditioning Laboratory	4-F
88	Mixing Laboratory	4-F
89	Laser Laboratory	4-F
90	Pyrotechnics Laboratory	4-E
97	Development Laboratory and Offices	4-E
98	Solid Fuel Laboratory	4-F
103	Fabrication Shop	5-F
107	Laser Research Laboratory	3-F
111	Technical Information	5-C
114	Electronics Development	5-D
117	Liquid and Solid Propellant Laboratory	3-E
121	Analytical Instruments Laboratory	3-G
122	Energy Conservation Systems	5-E
125	Combined Engineering Support	5-D
126	Information Systems Development	5-B
129	Combustion Research Laboratory	5-E
138	Mission Operations	4-D
140	Propulsion Materials Storage	3-E
141	Propulsion Materials Storage	3-E
143	Solid Rocket Dock	4-F
144	Environmental Laboratory	4-C
145	Magazine - Propellant	4-F
148	Energy Conservation Laboratory	4-D
149	Energy Conservation Development	3-D
150	25-Foot Space Simulator	4-C
156	Computer Program Offices	5-C
157	Applied Mechanics	6-D
158	Material Research Processing Laboratory	6-D
159	Pump House (water)	3-G
161	Telecommunications Laboratory	5-D
166	Cooling Tower	4-D
167	Cafeteria	6-C
168	Instrument System Laboratory	7-C
169	Earth Space Science	7-D
170	Fabrication Shop	7-D
171	Material Services	8-D
173	Test Shelter	3-G
175	Water Reservoir	2-F
177	Transportation Garage	5-E
179	Spacecraft Assembly Facility	7-C
180	Administration	5-C
183	Physical Science Laboratory	6-C
184	Electronic Stores	6-D
186	Programming Office	5-C
188	Science Exhibits and Engineering	7-B
189	Electronics Laboratory Annex	5-D
191	Procurement Offices	8-C
191	Materials Compatability Laboratory	3-G
195	Guard Shelter	7-C
196	Guard Shelter	5-B
197	Solid Propellant Engineering Laboratory	3-E
198	Control Systems Laboratory	6-D
199	Celestial Simulator	6-D
200	Facilities Engineering and Services	8-D
201	Carpenter Shop	8-C
202	Procurement and Communications Support	8-D
212	Antenna Laboratory	2-E
218	Credit Union	8-C
220	ICS Terminal	4-D
224	Sewage Lift Station	8-C
225	Nitrogen Facility Office	5-E
226	Solvent Storage	5-D
227	Pistol Range Storage	3-B
228	Cooling Tower (A-B)	4-B
229	Shielded Room Building	5-D
230	Space Flight Operation Facility	5-C
231	Paint Shop	8-D
233	System Development	7-C
234	Lumber Storage	3-E
237	Cooling Tower	5-C
238	Telecommunications	5-C
239	Propellant Conditioning Laboratory	3-F
241	Receiving and Shipping	8-D
243	Remote Antenna Range Control	1-C
244	Chemical Engineering	3-F
245	Spectroscopy Laboratory	4-B
246	Soils Test Laboratory	3-D
248	10-Foot Space Simulator	4-C
249	Visitor Reception	6-B
250	Main Guard Shelter	6-B
251	Gyro Laboratory	3-A
252	Guard Shelter	6-B
253	Magnetic Laboratory	3-A
256	Model Range Control	1-D
257	Main Guard Island	6-B
259	Water Reservoir	2-F
259	Liquid Nitrogen Bottling Storage	5-E
260	Illuminator Equipment	2-B
261	Controlled Storage	6-D
262	Radiometer	2-B

No.	Facility Title	Location
264	Space Flight Support	6-C
267	Water Reservoir	3-C
268	Pump House	3-C
270	Sewage Metering Station	7-B
271	Oil Storage	6-D
272	East Illuminator	2-E
273	Antenna Tower	2-E
275	Pyrotechnic Storage	3-E
276	Propellant Storage	3-E
277	Isotope Thermoelec. Sys. Appl. Lab.	4-F
278	Robotics Laboratory	6-D
279	Guard Island	7-C
280	Static Test Tower	4-E
283	Metal Storage	6-D
284	Transportation Office	5-E
285	Arroyo Bridge	3-G
286	Guard Shelter	3-G
287	Guard Island	3-G
288	Project Equipment Storage	4-E
289	Main Sewage Lift Station	7-B
290	Antenna Inspection	2-E
291	Procurement Services	8-C
293	Instrumentation Cable Amplifier Building	6-C
294	Guard Shelter (Visitor Lot)	6-B
295	Antenna Test Facility	1-E
296	Central Cooling Tower Water System	5-D
297	Xenon Test Laboratory	5-F
298	Frequency Standard Laboratory	4-A
299	Assembly Handling & Shpg. Equip. Fac.	4-D
300	Earth and Space Science Laboratory	5-E
301	Central Engineering Building	6-D
302	Microdevices Laboratory	5-F
303	Engineering Support Building	5-E
304	Disintegrator	6-D
305	Hazardous Waste/Cryogenic Storage Facility	4-E
306	Observational Instruments Laboratory	7-D
308	Sewage Lift Station	7-E
309	Maintenance Storage Facility	6-E
310	X X X	4-D
311	Ground Maintenance Facility	6-E
312	Shelter Maintenance Facility	4-D
313	Mirror Refurbishment	4-C
315	X X	8-D
316	Hazmat Storage and Dist Facility	4-E
317	In-situ Instruments Laboratory	5-E

MODULARS:

No.		Location
1701-1712	Modular Offices	4-D
1714	Modular Offices	4-C
1716	Modular Offices	4-C
1718	Modular Offices	5-C
1719	Modular Offices	6-C
1720	Modular Offices	6-D

Trailer Locations

Trlr.No.	Location
1021	4-B
1025	7-C
1028	4-B
1033	7-D
1044	4-G
1054	4-E
1057	7-D
1058	4-F
1060	7-D
1063	5-D
1065	7-C
1009	7-D
1073	7-D
1074	4-B
1076	4-G
1079	7-C
1081	4-F
1082	6-D
1085	7-C
1086	4-B
1087	4-B
1088	7-D
1089	4-B
1099	4-B
1102	4-F
1109	7-C
1110	7-C
1114	7-C
1128	3-D
1129	4-C
1132	7-D
1140	7-D
1141	7-D
1143	4-F
1147	7-D
1150	7-C
1151	7-D
1152	5-F
1153	4-G
1154	7-C
1155	7-C
1156	7-C
1162	5-D
1166	7-C
1167	6-C
1168	4-B
1169	7-D
1170	6-C
1173	7-C
1177	7-D
1180	7-D
1182	3-D
1186	7-D
1194	5-C
1197	7-D
1200	7-D
1201	5-F
1202	4-B
1203	7-D
1208	7-C
1213	5-C
1215	4-F
1300	7-D
1301	5-F
1304	5-F
1306	7-D
1307	7-D
1501	7-C
1502	5-F
1701	4-D
1702	4-D
1703	4-D
1704	4-D
1705	4-D
1706	4-D
1707	4-D
1708	4-D
1709	4-D
1710	4-D
1711	4-D
1712	4-D

N

0   250   500
Scale in Feet

JPLSITE02.CDR

3.2 Regional Demographics

Based on the United States Census 2000, the total population residing within 1 mile of JPL is 9,500 people. The population residing within 2 miles of JPL is 22,500 people, and the population residing within 3 miles is 44,000.

In 2001, the JPL workforce consisted of approximately 5,175 employees and contractors. Major sources of employment in the area surrounding JPL are office, retail, and service centers, primarily located within Pasadena. Residents of Altadena and La Cañada-Flintridge generally are employed outside their home community, except those conducting retail businesses or professional services for their respective communities.

In 2000, the population of Pasadena was approximately 133,936 and was broken down into the following demographics: 71,469 Caucasian; 19,319 Black or African-American; 952 American Indian; 13,399 Asian; 132 Pacific Islander; and 28,665 multiracial or other racial group.

In 2000, the population of Altadena was approximately 42,610 and was broken into the following demographics: 20,156 Caucasian; 13,388 Black or African-American; 247 American Indian; 1,807 Asian; 56 Pacific Islander; and 6,956 multiracial or other racial group. The population of La Cañada Flintridge in 2000 was approximately 20,318 and was broken into the following demographics: 15,142 Caucasian; 73 Black or African American; 36 American Indian; 4,180 Asian; 9 Pacific Islander; and 878 multiracial or other racial group.

According to the United States Census 2000, 33.4% of the Pasadena population identifies their ethnic group as Hispanic, while 20.4% of Altadena residents and 4.8% La Cañada Flintridge residents identify themselves as Hispanic.

3.3 Meteorology and Climatology

The San Gabriel Valley has a semiarid Mediterranean climate characterized by mild, relatively rainy winters and warm, dry summers. Rainfall in the area is variable, although it typically averages about 15 inches per year overall (Boyle Engineering, 1988). Rainfall in the vicinity of JPL is slightly higher than for the City of Los Angeles, averaging about 20 inches per year. The higher amount of rainfall near JPL results from the orographic effects generated along the southern slope of the San Gabriel Mountains. Roughly 80% of the precipitation occurs between the months of November and April.

Temperatures in the San Gabriel Valley are relatively mild, with August typically being the warmest month and January the coolest. Extremes for the area range from about 30°F in January to 105°F during the summer months. Wind patterns change seasonally in both strength and direction in response to normal seasonal variations in barometric pressure systems. Generally, winds are mild throughout the year, characterized by ocean breezes (onshore) during the day and land breezes (offshore) at night.

Occasionally during the fall, the area is affected by the Santa Ana winds. These winds occur as a result of strong high-pressure systems moving into parts of Nevada and Utah, creating strong,

hot, dry winds from the northeast. Santa Ana wind speeds through Arroyo Seco have reached more than 100 miles per hour.

3.4 Geology and Seismology

This section discusses the geology and seismology of the area surrounding JPL. Figure D-2 is a map of the regional geology and physiography. Figure D-3 is a geologic map of JPL and the surrounding area.

JPL is located immediately south of the southwestern edge of the San Gabriel Mountains (see Figure D-2). The San Gabriel Mountains, together with the San Bernadino Mountains to the east and the Santa Monica Mountains to the west, make up a major part of the east-west trending Transverse Ranges province of California. This province is dominated by north-south compressional deformation.

The San Gabriel Mountains are primarily composed of crystalline basement rocks. These rocks range in age from Precambrian to Tertiary and include various types of diorites, granites, monzonites, and granodiorites with a complex history of intrusion and metamorphism (Dibblee, 1982). The northwest part of the San Gabriel Valley, near JPL, is composed of about 1,500 to 2,000 ft of Cenozoic alluvial-fan deposits that unconformably overlie the crystalline basement complex exposed in the San Gabriel Mountains (Smith, 1986). These alluvial deposits typically consist of poorly sorted, coarse-grained sands and gravels, with some finer sand and silty material. Clasts within the alluvial deposits range from silt size to boulders more than 3 ft in diameter.

Periodic tectonic uplift of the San Gabriel Mountains has occurred during the past 1 to 2 million years. This uplift is responsible for the present topography of the area (Smith, 1986). Most of this uplift has occurred along north- to northeast-dipping reverse and thrust faults located along the south to southwest edges of the San Gabriel Mountains. This system of faults along the southern edge of the San Gabriel Mountains is the Sierra Madre Fault system. The Sierra Madre Fault system separates the San Gabriel Mountains to the north from the San Gabriel Valley to the south.

3.5 Hydrology

This section discusses the hydrology of JPL and the surrounding area. JPL is located in the northwest part of the Raymond Basin watershed (see Figure D-2).

3.5.1 Surface Water

There are no permanent surface water bodies within the boundaries of JPL. The northernmost part of JPL consists of Gould Mesa, a flat-topped southern promontory of the San Gabriel Mountains that rises 300 ft above the main part of the JPL complex. The remainder of JPL is moderately sloped and has been graded extensively throughout its development. The Arroyo Seco Creek intermittently flows through the Arroyo Seco wash on the east side of JPL. Within the Arroyo Seco, a series of surface impounments are used as surface water collection and spreading basins for groundwater recharge.
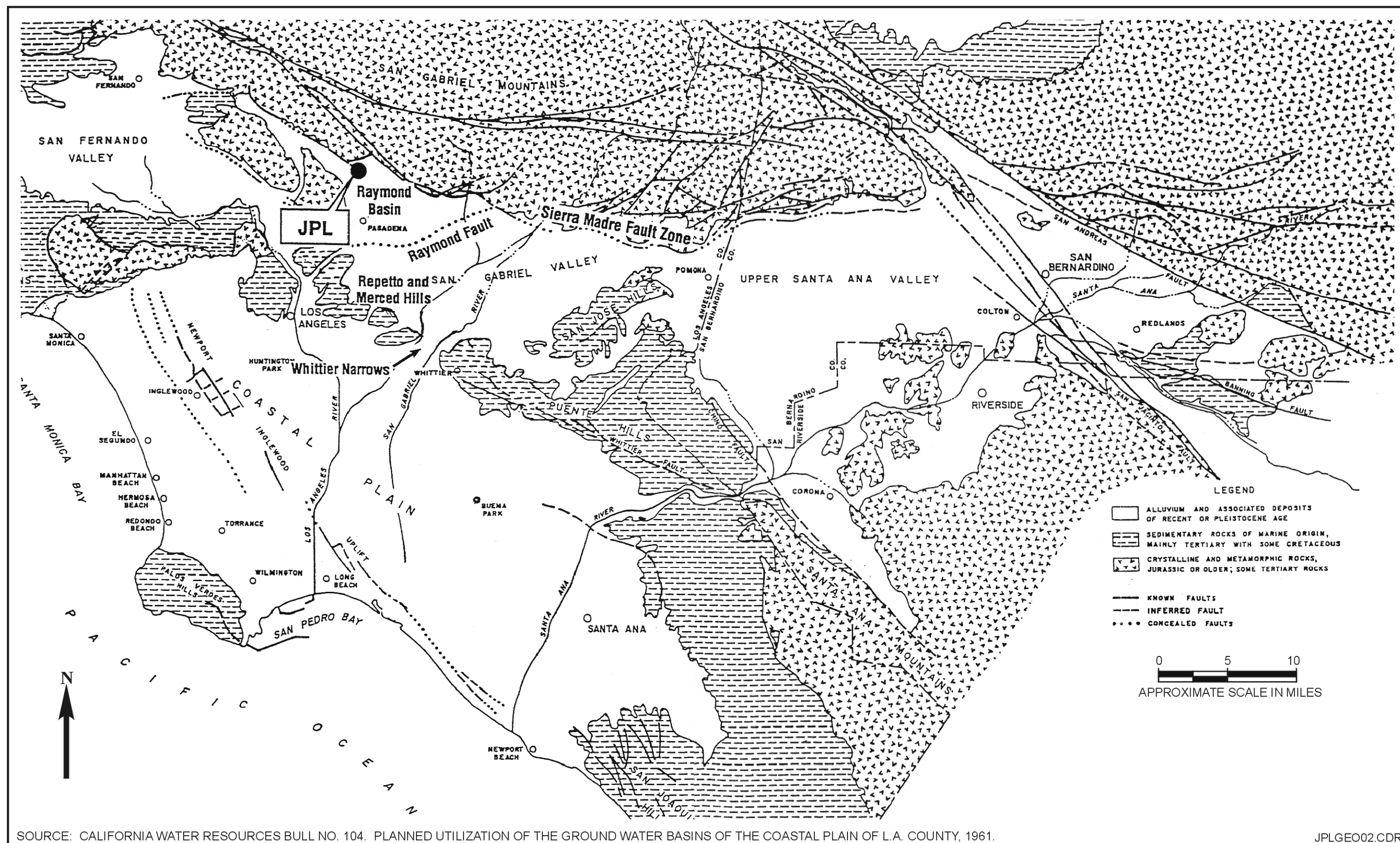
Figure 2. Map of Regional Geology and Physiography
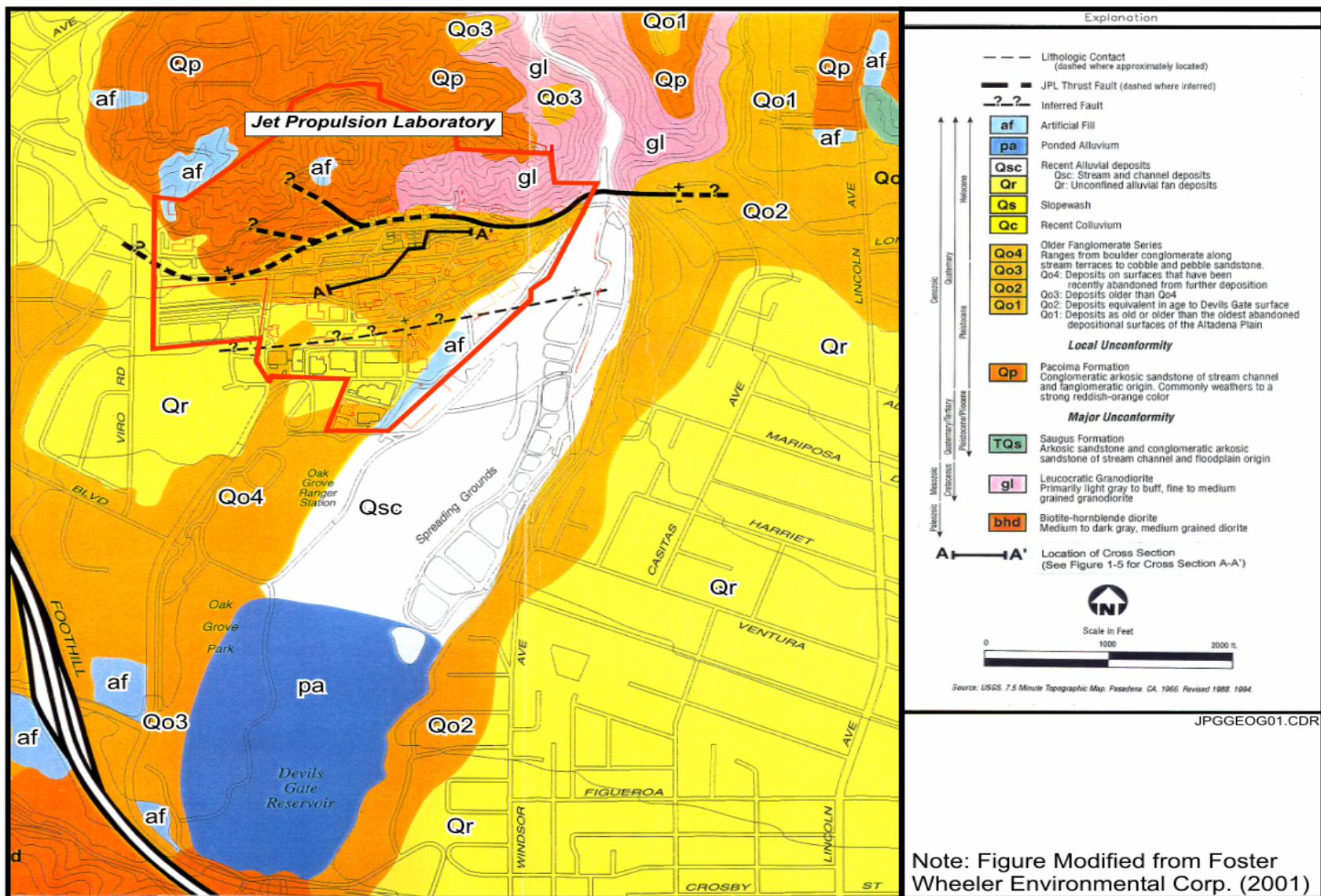
JPLGEO02.CDR

Figure 3. Geologic Map of the JPL and Surrounding Area

3.5.2 *Groundwater*

The San Gabriel Valley contains distinct groundwater basins, including the Raymond Basin, where JPL is located (see Figure D-2). The Raymond Basin is bordered on the north by the San Gabriel Mountains, on the west by the San Rafael Hills, and on the south and east by the Raymond Fault. The Raymond Basin provides an important source of potable groundwater for many communities in the area around JPL, including Pasadena, La Cañada-Flintridge , San Marino, Sierra Madre, Altadena, Alhambra, and Arcadia.

North of the JPL Thrust Fault (see Figure D-3), groundwater primarily occurs in joints and fractures in the bedrock. Because the bedrock is of low porosity, it is considered non-water-bearing. South of the JPL Thrust Fault, groundwater occurs in alluvial deposits.

The aquifer below JPL consists of four layers that are separated by noncontiguous, low-permeability silt layers (see Figure D-4). Layer 1 consists of the upper 75 to 100 ft of saturated alluvium. Layer 2 underlies Layer 1 and is about 150 to 200 ft thick. Layer 3 is about 200 to 300 ft thick and generally overlies crystalline basement rock beneath JPL. Layer 4 occurs only at the far eastern end of JPL, is about 150 ft thick, and rests on crystalline basement rocks.

Depth to groundwater at JPL ranges from 22 ft bgs to 270 ft bgs. This wide range of depth to water is attributed to steep topography in the northern part of the site and to seasonal groundwater recharge. The depth to groundwater under most of the JPL complex averages approximately 200 ft.

3.6 Natural and Ecological Resources

JPL is located along the northern edge of the San Gabriel Valley in the central part of Los Angeles County. The San Gabriel Valley is bounded to the north by the San Gabriel Mountains, which consist of relatively steep, rocky ridges with numerous canyons. The northernmost part of JPL consists of Gould Mesa, a flat-topped, southern promontory of the San Gabriel Mountains that rises 300 ft above the main JPL complex. Chaparral covers the convex slopes of the mesa in this part of JPL as well as the upland banks of the Arroyo Seco, east of JPL.

The Arroyo Seco, which borders the east side of JPL, is about 1,000 ft wide. It contains mostly riparian and desert wash habitat, interspersed with chaparral. The Arroyo Seco Creek intermittently flows through the Arroyo Seco wash. The Arroyo Seco collects runoff from the north, east, and west. Several groundwater recharge ponds are located on the east side of the Arroyo Seco and west of the extended parking area (see Figure D-3). Groundwater beneath the Arroyo Seco is a current source of drinking water.

Riparian areas are located directly northeast and east of the JPL along the Arroyo Seco Creek. Riparian trees are thicker at the drain outfalls on the eastern boundary of JPL, where runoff from landscaped areas and pavement is year-round. However, there are no forest resources at JPL.

The predominant habitat type at JPL is urbanized landscape, with paved roads, parking lots, and buildings. Vegetation used in landscaping includes native and nonnative plant species.

Figure 4. Conceptual Model of JPL Aquifer Layers

NOTE: GRAPHIC PREPARED BY FOSTER WHEELER ENVIRONMENTAL CORPORATION (2001).

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Species of special concern that potentially occur in the vicinity of JPL include the southwestern arroyo toad, the southwestern pond turtle, the San Diego horned lizard, the peregrine falcon, the bank swallow, the western yellow-billed cuckoo, and the least Bell's vireo. These species were identified using the California Department of Fish and Game Natural Diversity Database (California Department of Fish and Game, 1995) and the California Native Plant Society's list of rare, threatened, or endangered plant species (Skinner and Paulik, 1994). However, none of these species have been identified at the JPL site. If necessary, consultation under Section 7 of the Endangered Species Act will be conducted directly with the U.S. Fish and Wildlife Service.

3.7 Archaeological and Cultural Resources

NASA has an obligation to determine if any building, structure, or object listed or eligible to be listed on the National Register of Historic Places would be affected by the OU-1 remedial activities. It also has the obligation to determine whether any historical or archaeological data could be destroyed through alteration of terrain as a result of implementation of the selected remedial action.

It is unlikely that property with historic, architectural, archaeological, or cultural value located within the vicinity of JPL will be impacted by the selected remedial action. However, a historical, archaeological, architectural, and cultural resource review of surrounding and on-facility property will be conducted prior to implementation if remedial actions involve intrusive groundwork.

4: NEPA VALUES ASSESSMENT OF PROPOSED ACTION
AND ALTERNATIVES

The results of groundwater investigations conducted at JPL revealed the presence of VOCs and perchlorate above health-based levels. These chemicals have the potential to migrate off-facility, thus impacting downgradient groundwater sources.

Under the NFA alternative, no remediation of OU-1 would be planned except that which occurs naturally due to chemical/biological degradation, dispersion, advection, and sorption. The NFA alternative would not prevent migration of perchlorate and VOCs in the groundwater to off-site drinking water sources.

Under the selected alternative, ex situ biological treatment of perchlorate and ex situ LGAC treatment of VOCs would be used to remediate the source area groundwater at OU-1. The treatment systems would operate until the performance objectives are achieved.

Air emissions from ex situ biological treatment of perchlorate and ex situ LGAC treatment of VOCs would be limited to possible dust generation during well installation and pipeline construction. The dust generation during well installation would be minimal and occur over a short duration; therefore, these emissions are expected to have negligible impacts on local air quality. The VOCs and perchlorate in the extracted groundwater will be removed by an above ground treatment system in accordance with state and local ARARs. These ARARs ensure protection of human health and the environment.

The ex situ biological treatment of perchlorate and ex situ LGAC treatment of VOCs system expansion and operation would also result in negligible impacts. Any vegetation removed or species temporarily displaced would have the potential to recolonize the area following completion of the construction. However, given the small size of the above ground system, the net impact to wildlife species would be negligible.

Solid waste, in the form of spent carbon from the LGAC treatment system and sludge from the bioreactor, would be transported and treated off site. Thus, implementation of the selected alternative would have negligible impacts and during operation would be protective of human health and the environment.

In addition, because the ex situ biological treatment of perchlorate and LGAC treatment of VOCs system permanently removes perchlorate and VOCs from the groundwater, the potential for further groundwater contamination to off-site is significantly reduced. Thus, long-term protection and reliability are provided to the environment.

4.1 Socioeconomic Impacts

Expansion and continued operation of the ex situ biological treatment of perchlorate and LGAC treatment of VOCs system at OU-1 is expected to employ a maximum of five people on a part-time, temporary basis. Operation and maintenance of the system is expected to employ one person full time. These numbers are small compared to the total present employment at JPL (approximately 5,175), as well as employment at local businesses and industries in the surrounding area.

The workforce needed to implement the selected alternative would be derived from local construction companies. No measurable impact on the local economy would be expected. Thus, direct and indirect socioeconomic impacts of the remediation of OU-1 using the selected alternative are expected to be negligible.

The NFA alternative would have no direct socioeconomic effects on JPL or the surrounding area. However, because no action would be taken under the NFA alternative to protect the beneficial uses of the groundwater at JPL, potential indirect socioeconomic effects could accrue to JPL and the surrounding area due to the degradation of groundwater quality.

4.2 Transportation Impacts

Three major freeways serve the Pasadena, Altadena, and La Cañada Flintridge communities (see Figure D-3). The Pasadena Freeway (California Route 110) connects Pasadena to Los Angeles. The Foothill Freeway (Interstate 210) links communities to the north and east of Pasadena. The Ventura Freeway (U.S. Route 134) leads to Ventura County and beyond.

OU-1 source area groundwater remediation at JPL using the selected alternative would create a very small, short-term increase in traffic flow to and from the site as a result of the movement of equipment and supplies. However, based on current traffic volume associated with the 5,175 JPL employees and various activities, the increased traffic associated with remediation efforts under the selected alternative would be negligible.

Most of the traffic on and around JPL is associated with morning and evening rush hours, 7:00 to 9:00 a.m. and 4:00 to 6:00 p.m. Most of the traffic associated with the movement of equipment and supplies for the selected alternative would not be present at those peak periods of traffic flow. Further, all truck traffic associated with implementation of the selected alternative would be during daylight hours, which would further reduce the potential for accidents. Similarly, removal and transport of spent carbon and sludge waste during daylight, non-rush hours are expected to have a negligible impact over the entire course of treatment.

The NFA alternative would have no effects on transportation at JPL or in the surrounding area.

4.3 Natural and Ecological Resources

Groundwater beneath the JPL is a current source of drinking water. The selected alternative for OU-1, on-facility groundwater at JPL, is expected to have a beneficial effect on groundwater near JPL. No threatened or endangered species have been identified at the JPL site.

The areal extent of VOCs and perchlorate in the groundwater and the proposed area for installation and operation of the ex situ treatment system are located within the main JPL complex in previously disturbed and developed areas. These areas contain no wetlands and provide minimum wildlife habitat. The minimal land disturbance caused by installation of the ex situ treatment system is expected to have negligible impacts on vegetation and wildlife.

There is no floodplain or wetland involvement in the response action for OU-1; therefore, a floodplains/wetlands assessment is not required.

Under the NFA alternative, no action would be taken to protect the beneficial uses of the groundwater at JPL. Thus, the NFA alternative would have no effects on natural or ecological resources at JPL or in the surrounding area.

4.4 Environmental Justice

Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations, directs federal agencies to identify and address, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority and low-income populations.

As part of the RI (FWEC, 1999), NASA conducted a human health risk assessment (HHRA) to determine the need for action to protect human health. The HHRA assessed cancer and noncancer risks associated with human exposure to untreated groundwater, which represents the only direct human exposure route at OU-1. Conservative assumptions with respect to VOCs, perchlorate, and other chemical concentrations in groundwater, exposure parameters, and toxicity ensured that the calculated risks were protective of human health. Exposure parameters included both commercial and residential land use scenarios and risks were assessed for on-facility human receptors.

The results of the HHRA showed that the risks associated with exposure to groundwater are negligible and are within regulatory thresholds. The Agency for Toxic Substances and Disease Registry (ATSDR) has determined that on-facility and off-facility groundwater at JPL does not pose a present or future public health hazard because wellhead treatment and water blending are used by local water purveyor to meet stringent drinking water standards prior to distribution of water for public use (ATSDR, 1999).

The risks from implementation of the ex situ biological treatment of perchlorate and LGAC treatment of VOCs are low. Therefore, NASA expects little to no adverse human health impacts from implementation of the selected alternative to occur in any off-facility community, including minority and low-income communities.

4.5 Irreversible and Irretrievable Commitment of Resources

The commitment of a resource is considered irreversible if primary or secondary impacts of the response action limit future options for the use of the resource. Under the selected action, LGAC would be used to remove VOCs and a biological fluidized bed reactor (FBR) would be used to remove perchlorate from groundwater at JPL. The primary objective of ex situ biological treatment of perchlorate and LGAC treatment of VOCs would be to reduce the potential for further groundwater impacts downgradient of the JPL facility. Thus, under the selected action, there would be no irreversible commitment of resources. Rather, groundwater would be recovered as a resource under this action.

The commitment of a resource is considered irretrievable if the action uses or consumes the resource during the course of implementation. Again, under the selected action, the ex situ biological treatment of perchlorate and LGAC treatment of VOCs would be conducted to remove perchlorate and VOCs from the groundwater and reduce the potential for further groundwater impacts. The treated groundwater would be re-injected. This action would lead to potential recovery of the groundwater resource. Thus, under the selected action there would be no irretrievable commitment of resources.

4.6 Cost-Benefit Analysis

Costs associated with the selected action, expansion and continued operation of the OU-1 source area demonstration system, were evaluated in the Interim ROD. Capital costs associated with the technology include installation of one extraction well and one injection well, and associated piping. In addition, LGAC vessels, one FBR unit, the substrate and nutrient feed system, a multimedia filter, and a backwash and a biomass collection is included in the existing treatment system. Operating and maintenance costs include operation and maintenance of the treatment system. Total present worth cost for the selected action is estimated to be $8,980,000.

NASA and the regulatory authorities agree that the costs associated with ex situ biological treatment of perchlorate and LGAC treatment of VOCs in groundwater are justified because the selected action reduces and removes VOCs and perchlorate from the on-site groundwater at JPL and reduces the potential for off-site groundwater impacts. Thus, the groundwater resource at JPL is recovered, and the groundwater beneath JPL is protected, as required under both the NCP (40 CFR Section 300.430(e)(2)(B)) and State of California regulations for the beneficial use of groundwater, including groundwater used as a source of drinking water.

5: CUMULATIVE IMPACTS

As described above, minimal environmental impacts are expected from the proposed implementation of the selected action. In particular, the selected action would have no adverse impacts on threatened or endangered species, cultural resources, floodplains, or wetlands. NASA expects no adverse human health impacts from the CERCLA action to occur in any off-facility community, including minority and low-income communities. Under the selected action, increases in JPL traffic would be minimal and consist of transportation of equipment and supplies to and from the JPL site, resulting in insignificant transportation impacts. There would be no measurable impact on the local economy as a result of the selected action, and, thus, no socioeconomic impacts are anticipated. Also, under the selected alternative, there would be no irreversible and irretrievable commitment of resources and the cost of remediation is justified to protect the existing source of drinking water.

NASA has examined the potential cumulative environmental impacts of the selected action in addition to other past, present, and reasonably foreseeable future actions at the site. NASA has initiated cleanup activities to address VOC- impacted soil for on-facility (OU-2) and VOC-and perchlorate-impacted groundwater for off facility (OU-3). Response actions have been and will continue to be conducted in accordance with all federal, state, and local regulations. Also, research and development related to robotic exploration of the solar system, remote sensing, astrophysics, and planetary science is performed at JPL. These activities are conducted in controlled settings in accordance with applicable regulations. NASA does not anticipate any cumulative environmental impacts from the activities conducted at JPL and remedial activities at OU-1. Rather, the remediation of OU-1, using ex situ biological treatment of perchlorate and LGAC treatment of VOCs would have a positive impact in preventing further negative impacts to the groundwater resource.

6: AGENCIES AND PERSONS CONTACTED

During the preparation of the RI (FWEC, 1999) and the Interim ROD for OU-1, NASA consulted with and received comments and recommendations from the Cal-EPA DTSC; RWQCB, Los Angeles Region; the EPA, Region IX; the U.S. Fish and Wildlife Service; and the Raymond Basin Management Board. In addition, the Naval Facilities Engineering Command (NAVFAC), the City of Pasadena, and the Lincoln Avenue Water Company are also providing technical assistance to NASA on cleanup decisions at JPL.

7: REFERENCES

Boyle Engineering. 1988. *Jet Propulsion Laboratory Facilities Master Plan*.

California Department of Fish and Game. 1995. *Natural Diversity Data Base*. September.

Department of Justice. 1995. "Agreed to Report of March 31, 1994 Meeting Regarding the Application of NEPA to CERCLA Cleanups." Memorandum from L.J. Schiffer, Assistant Attorney General, Environment and Natural Resources Division of DOJ, Washington, DC. January 23.

Dibblee, T.W., Jr. 1982. "Geology of the San Gabriel Mountains, Southern California." In D.L. Life and J.A. Minch (Eds.), *Geology and Mineral Wealth of the California Transverse Ranges*. South Coast Geological Society. pp. 131-147.

DOJ, see Department of Justice.

Ebasco. 1990a. *Expanded Site Inspection Report for NASA-Jet Propulsion Laboratory, Pasadena, California*. May.

Ebasco. 1990b. *Supplemental Information to the Expanded Site Inspection Report for NASA-Jet Propulsion Laboratory, Pasadena, California*. November.

EPA, see United States Environmental Protection Agency.

Foster Wheeler Environmental Corporation. 1999. *Final Remedial Investigation Report for Operable Units 1 and 3: On-site and Off-site Groundwater*. National Aeronautics and Space Administration Jet Propulsion Laboratory, Pasadena, CA. August.

FWEC, see Foster Wheeler Environmental Corporation.

National Aeronautics and Space Administration. 1994. *Final Superfund Community Relations Plan*. Prepared by NASA's Jet Propulsion Laboratory. NAS7.000794, NASA-JPL, SSIC No. 9661. January.

NASA, see National Aeronautics and Space Administration.

Skinner, M.W., and B.M. Paulik (Eds.). 1994. *California Native Plant Society Inventory of Rare and Endangered Vascular Plants of California*. California Native Plant Society, Sacramento, CA.

Smith, D.P. 1986. *Geology of the North Half of the Pasadena Quadrangle, Los Angeles County, California*. California Division of Mines and Geology Open File Report 86-4 LA.

United States Environmental Protection Agency. 1992. "United States Environmental Protection Agency Region 9 and the California State Department of Toxic Substances Control and the California Regional Water Quality Control Board and the National Aeronautics and Space Administration, in the Matter of: The United States National Aeronautics and Space Administration Jet Propulsion Laboratory, Federal Facility Agreement Under CERCLA Section 120." Prepared by EPA, Region 9.